The WELDING JOURNAL

AUGUST 1952

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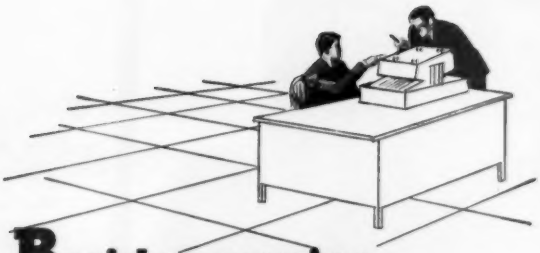

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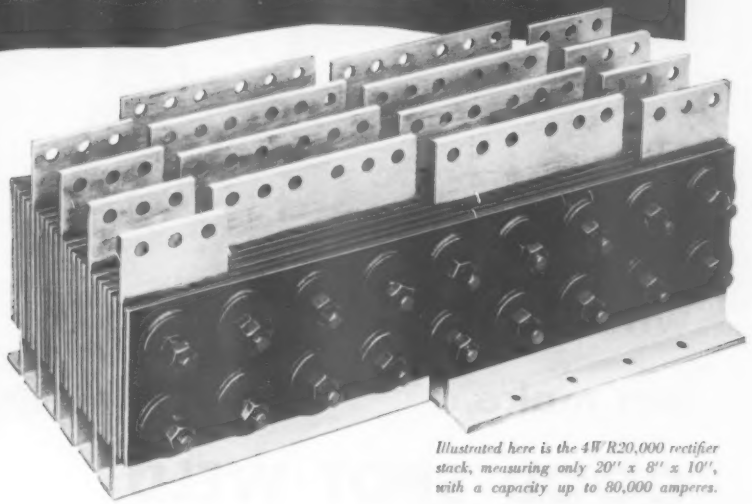

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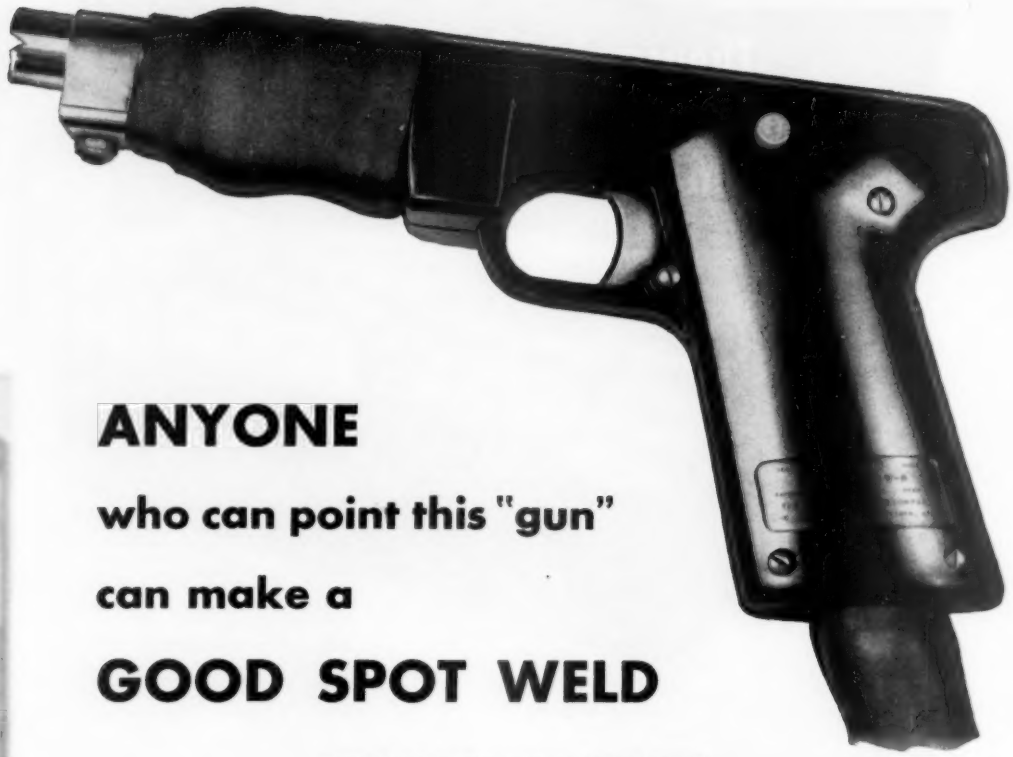

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Published for the advancement of the science and art of welding by the AMERICAN WELDING SOCIETY

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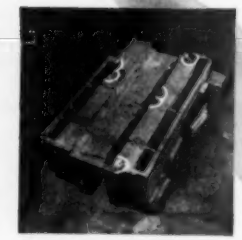

Casting ready for welding. Defects have been chipped out with pneumatic tool and circled with chalk.

Welder depositing Ni-Rod "55" in cavity. Successive beads will be laid in each cavity up to the proper level of the surrounding cast iron casting.

How 7 lbs. of Ni-Rod "55" saved a 600 lb. casting

Finished welds in pump casting. Defects in 600 lb. casting have been corrected with only 7 lbs. of Ni-Rod "55".

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67 Wall Street, New York 5, N. Y.

The WELDING JOURNAL

volume 31 August 1952 number 8

Proposed Tentative Specifications for Brazing Filler Metals*

***IMPORTANT:** These Specifications were prepared by Subcommittee VIII—Brazing Filler Metal, of the Committee on Filler Metal jointly sponsored by the AMERICAN WELDING SOCIETY and the American Society for Testing Materials. They have been approved by Subcommittee VIII and the Committee but have not yet been adopted by both societies. Pending such adoption they are being published here as a matter of information only.*

Scope

1. These Specifications cover brazing filler metals.

Classification

2. The brazing filler metals are classified on the basis of their chemical composition as manufactured.

Manufacture

3. The brazing filler metals may be made by any method that will yield a product conforming to the requirements of these Specifications.

Chemical Composition

4. (*a*) The brazing filler metals shall conform to the chemical composition shown in Table 1 for the classification in which they are to be included.

(*b*) The method of chemical analysis shall conform to the requirements of ASTM "Methods of Chemical Analysis of Metals," latest edition.

Mechanical Properties

5. These Specifications do not cover the mechanical properties of either the filler metal or the joint.

Standard Forms, Sizes and Tolerances

6. (*a*) Standard forms and sizes are as shown in Table 2.

(*b*) Standard tolerances are as shown in Table 3.

Packaging

7. The brazing filler metals shall be suitably wrapped, boxed or otherwise packaged to protect against injury during shipment or under normal dry storage conditions.

Marking

8. (*a*) All packages containing rods, containers containing powder or formed shapes, and coils of wire or strip shall be legibly labeled or tagged with the following information:

1. Classification.
2. Manufacturer's name and trade designation.
3. Size, length and net weight.
4. Guarantee.

(*b*) Each rod 1/8 in. in diameter and larger shall be marked with the classification number.

* Under the standardization procedure of the issuing societies, these specifications are under the jurisdiction of the AWS-ASTM Committee on Filler Metal.

By publication of these specifications, the issuing societies do not undertake to insure anyone utilizing the specifications against liability for infringement of letters patent or assume any such liability and such publication should not be construed as a recommendation of any patented or proprietary material or application that may be involved.

Table 1—Chemical Requirements

Note 1: Analysis shall be made for the elements for which specific values are shown in in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "Other elements—total" in the last column in the table.

Note 2: Single values shown are maximum percentages, except where otherwise specified.

Aluminum-silicon

AWS-ASTM classification	Si	Cu	Fe	Zn	Mg	Mn	Cr	Ti	Al	Other elements—each	Other elements—total
BAlSi-1	4.0–6.0	0.30	0.80	0.10	0.05	0.05	..	0.20	Remainder	0.05	0.15
BAlSi-2	6.8–8.2	0.25	0.80	0.20	...	...	...	..	Remainder	0.05	0.15
BAlSi-3	9.3–10.7	3.3–4.7	0.80	0.20	0.15	0.15	0.15	..	Remainder	0.05	0.15
BAlSi-4	11.0–13.0	0.30	0.80	0.20	0.10	0.15	..	..	Remainder	0.05	0.15

Copper-phosphorus

AWS-ASTM classification	P	Ag	Cu	Other elements—total
BCuP-1	4.75–5.25	.....	Remainder	0.15
BCuP-2	6.75–7.50	.....	Remainder	0.15
BCuP-3	6.00–6.50	4.75–5.25	Remainder	0.15
BCuP-4	6.75–7.80	5.75–6.25	Remainder	0.15
BCuP-5	4.75–5.25	14.50–15.50	Remainder	0.15

Silver

AWS-ASTM classification	Ag	Cu	Zn	Cd	Ni	Sn	Other elements—total
BAg-1	44–46	14–16	14–18	23–25	...	...	0.15
BAg-2	34–36	25–27	19–23	17–19	...	...	0.15
BAg-3	49–51	14.5–16.5	13.5–17.5	15–17	2.5–3.5	...	0.15
BAg-4	39–41	29–31	26–30	...	1.5–2.5	...	0.15
BAg-5	44–46	29–31	23–27	...	...	...	0.15
BAg-6	49–51	33–35	14–18	...	...	...	0.15
BAg-7	55–57	21–23	15–19	...	...	4.5–5.5	0.15
BAg-8	71–73	27–29	...	...	...	...	0.15
BAg-9	64–66	19–21	13–17	...	...	...	0.15
BAg-10	69–71	19–21	8–12	...	...	...	0.15
BAg-11	74–76	21–23	2.5–3.5	...	...	...	0.15

Copper-gold

AWS-ASTM classification	Au	Cu	Other elements—total*
BCuAu-1	37.25–37.75	Remainder	0.005
BCuAu-2	79.75–80.25	Remainder	0.005

Copper and copper-zinc

AWS-ASTM classification	Cu	Sn	Fe	Mn	Ni	P	Pb	Al	Si	Ag	Zn	Other elements—total
BCu	99.90 min.†	...	...	...	...	0.075	0.02	0.01	..	...	...	0.10
BCuZn-1	58.0–62.0	...	...	...	...	...	0.05	0.01	...	...	Remainder	0.50
BCuZn-2	57.0 min.	0.25–1.0	...	...	...	...	0.05	0.01	...	...	Remainder	0.50
BCuZn-3‡	56.0 min.	1.1	0.25–1.25	1.0	1.0	...	0.05	0.01	0.25	...	Remainder	0.50
BCuZn-4	50.0–55.0	...	0.10	...	...	...	0.50	...	...	...	Remainder	0.50
BCuZn-5	50.0–53.0	3.0–4.5	0.10	...	...	...	0.50	...	...	...	Remainder	0.50
BCuZn-6	46.0–50.0	...	0.25	...	9.0–11.0	...	0.05	0.005	0.15	...	Remainder	0.50
BCuZn-7	46.0–48.0	...	...	...	10.0–11.0	0.20–0.50	...	...	0.15	0.30–1.00	Remainder	0.10

Magnesium

AWS-ASTM classification	Al	Mn	Zn	Si	Cu	Ni	Mg	Other elements—total
BMg	8.3–9.7	0.10 min.	1.7–2.3	0.3	0.05	0.01	Remainder	0.03

Heat-resisting materials

AWS-ASTM classification	Ni	Cr	B	Fe	Si	C	Ag	Mn	Other elements—total
BNiCr	65–75	13–20	2.75–4.75	§	§	§	...	...	0.50
BAgMn	...	...	...	...	...	...	84–86	14–16	0.15

* These alloys shall not contain more than 0.005% volatile impurities such as zinc or cadmium, and should be available oxygen free, if so specified by the purchaser.

† Copper plus silver.

‡ RCuZn-B and RCuZn-C welding rod (see AWS Specifications for Copper and Copper Alloy Welding Rod) meet these requirements. BCuZn-3 brazing filler metal can be used as RCuZn-B or RCuZn-C welding rod only if it meets the specification requirements of these rods.

§ Total Fe + Si + C = 10.0 max.

(*c*) Wire and strip coils shall be marked at each end with the classification number.

(*d*) Flat strip and sheet shall be marked at intervals of not more than 18 in. on at least one side with the classification number.

Table 2—Standard Forms and Sizes

AWS-ASTM classification	*Standard form*	*Size, in.*
Aluminum-silicon		
BAlSi-1, BAlSi-3	Strip	0.020 x 2
	Wire in coils	Round, 1/16 to 3/16
	Rod	Round, 1/16 to 1/4 x 18 to 36
BAlSi-2	Coated sheet	0.006 to 1/4*
BAlSi-4	Strip	0.020 x 2
	Wire in coils	Round, 1/16 to 3/16
Copper-phosphorus		
BCuP-1	Strip	0.005 to 0.015 x 1 1/4
BCuP-2	Wire in coils	Round, 1/16 to 3/16
		Square, 1/8 to 3/16
	Rod	Round, 1/16 to 1/4 x 18 to 36
		Square, 1/8 to 1/4 x 18 to 36
	Powder	50 to 325 mesh
BCuP-3	Wire in coils	Round, 0.047 to 1/8
	Rod	Round, 1/16 to 1/4 x 18 to 36
	Powder	50 to 325 mesh
BCuP-4	Wire in coils	Round, 0.047 to 3/16
		Square, 1/8 to 1/4
	Rods	Round, 1/16 to 1/4 x 18 to 36
		Square, 1/8 to 1/4 x 18 to 36
	Powder	50 to 325 mesh
BCuP-5	Strip	0.003 to 0.025
	Wire in coils	Round, 0.010 to 1/4
		Square, 1/8 to 1/4
	Rods	Round, 1/32 to 1/4 x 18 to 36
		Square, 1/8 to 1/4 x 18 to 36
	Powder	50 to 325 mesh
Silver		
BAg-1, BAg-2, BAg-3, BAg-4, BAg-5, BAg-6, BAg-7, BAg-8, BAg-9, BAg-10, BAg-11	Strip	0.003 to 0.025
	Wire in coils	Round, 0.010 to 3/16
		Square, 1/8 to 3/16
	Rod	Round, 1/16 to 1/4 x 18 to 36
		Square, 1/8 to 1/4 x 18 to 36
	Powder	50 to 325 mesh
Copper-gold		
BCuAu-1, BCuAu-2	Strip	To order
	Wire in coils	To order
Copper and copper-zinc		
BCu, BCuZn-1, BCuZn-2, BCuZn-3	Strip	0.004 to 0.025
	Wire in coils	Round, 0.003 to 1/4
	Rod	Round, 1/16 to 3/8
BCuZn-4	Grain	3 to 40 mesh
BCuZn-5	Grain	3 to 70 mesh
BCuZn-6	Strip	0.006 to 0.025
	Wire in coils	Round, 1/16 to 1/4
	Rod	Round, 1/32 to 1/4 x 18 to 36
BCuZn-7	Strip	0.006 to 0.025
	Wire in coils	Round, 1/16 to 1/4
	Rod	Round, 1/16 to 1/4 x 18 to 36
	Powder	40 to 180 mesh
Magnesium		
BMg	Wire in coils	Round, 3/64 to 3/16
	Rod	Round, 3/64 to 3/16 x 18 to 36
Heat-resisting materials		
BNiCr	Strip	0.005 to 0.020
	Wire in coils	Round, 1/16 to 1/4
	Powder	325 mesh
BAgMn	Strip	0.003 to 0.025
	Wire in coils	Round, 0.010 to 1/4
	Rods	Round, 1/16 to 1/4 x 18 to 36

* Coated on one or both sides; coating varies from 5 to 10% of thickness of base metal sheet; several aluminum alloy base metals available.

Table 3—Dimensional Tolerances on Wire, Rod, Strip and Sheet

Size, in.	*Tolerances, in.*	
Drawn wire, diam. (round) or width (square)	Round	Square
0.010 to 0.020, incl.	±0.0003	...
Over 0.020 to 0.030	0.0005	...
0.030 to 0.040	0.0007	...
0.040 to 0.050	0.0008	...
0.050 to 0.060	0.0010	...
0.060 to 0.080	0.0015	...
0.080 to 0.250	0.0020	±0.004
Drawn rod, diam. (round)		
0.060 to 0.375, incl.	±0.002	...
Rolled or extruded rod and wire, diam. (round) or width (square)		
1/32 to 1/16, incl.	±0.005	...
Over 1/16 to 1/8	0.006	...
1/8 to 3/16	0.007	±0.009
3/16 to 1/4	0.008	0.010
Strip or sheet, thickness	To 8 in. wide, incl.	Over 8 in. wide
Through 0.006	±0.0006	Standard strip and sheet tolerances apply
Over 0.006 to 0.013	0.0010	
0.013 to 0.021	0.0015	
0.021 to 0.026	0.0020	

Guarantee

9. The manufacturer shall guarantee that the brazing filler metals in all sizes and classifications conform to these Specifications and each container shall be so marked. The manufacturer's responsibility shall be limited to replacement of any filler metal which does not conform to the requirements of these Specifications.

APPENDIX

Guide to AWS-ASTM Classification of Brazing Filler Metals

PART I—INTRODUCTION

Brazing filler metals, simply speaking, are metals that are added when making a braze. They have melting points below those of the metals being brazed; they have properties suitable for making joints between closely fitted surfaces by capillary flow.

Brazing filler metals have become available in increasing numbers and now can be standardized into seven fairly well-defined classifications. These include the silver, the copper and copper-zinc, the copper-phosphorus, the aluminum-silicon, the magnesium, the copper-gold and the heat-resisting filler metals.

These Specifications are intended to provide both the manufacturer and the user of brazing filler metal with a means of production control and bases of acceptance through mutually acceptable standard requirements. The Specifications classify only those filler metals in common use at the time of issue. Other brazing filler metals were omitted since their volume of use was not considered sufficient to warrant inclusion. Some of these however, may be included in later revisions of these Specifications, as usage increases.

This Guide is appended to the Specifications as a source of information; *it is not mandatory and does not form a part of the Specifications.* It has been prepared as an aid to users of brazing filler metals, to help them determine what classification of brazing filler metal is best for a particular job.

The seven basic classifications of brazing filler metal are identified, as shown in Table 1 of these Specifications, by the principal element or elements in their chemical composition. In a typical example, such as BCuZn-2, for instance:

B is for brazing filler metal (like the E is for electrodes and the R for welding rods in other AWS-ASTM Specifications);

CuZn is for copper-zinc, the two principal elements in this particular brazing filler metal. (In a similar way, in other brazing filler metals, Si is for silicon, P for phosphorus, Ag for silver, etc., using standard chemical symbols.

2 is for one particular chemical analysis within a group (1 is another analysis within the same group, 3 another, etc.).

The brazing processes are widely used to join most metals and alloys, in similar and dissimilar combinations. In many instances, brazing permits increased production of quality joints at relatively low costs. The joints are neat and strong, may be gas and pressure tight, can have high electrical and thermal conductivity and good corrosion resistance.

In this Guide solidus and liquidus temperatures are specified instead of melting and flow points. This is done to avoid confusion. The terms solidus and liquids are well established in metallurgical usage. Their definitions are as follows:

Solidus—The highest temperatures at which the metal is completely solid; in other words, the temperature at which melting starts.

Liquidus—The lowest temperature at which the metal is completely liquid; in other words, the temperature at which freezing starts.

Note that the solidus and liquidus temperatures for a particular metal are definite and fixed. On the other hand melting point and flow point tend to be ambiguous. In general practice, these terms are defined as follows:

Melting point—The temperature below which an alloy is substantially solid.

Flow point—The temperature above which the alloy is liquid and will run or flow.

However, these definitions are at times not followed and also are not in themselves very definite. Hence, solidus and liquidus are preferred. Table A in this Guide lists the solidus, liquidus and also the recommended brazing temperature range for the various brazing filler metals.

When brazing with some brazing filler metals (particularly those with a wide temperature range between solidus and liquidus), the several constituents of the filler metals tend to separate during the melting process. The lower melting constituent will flow, leaving behind a *skull* of the high melting constituent. This occurrence, called *liquation*, is undesirable since the unmelted *skull* does not contribute significantly to the actual brazed joint: it does not flow into the joint. However, where fit-up is not too good, a filler metal with a wide temperature range will usually fill the joint more easily.

When brazing with any of the various processes, prebraze cleaning of the base metal is essential. The surface should be free from grease, oxides, scale and dirt of any kind. Cleaning can be done chemically or mechanically. Grease or oil can be removed by a reliable degreasing solution such as trichloroethylene, carbon tetrachloride or trisodium phosphate. Oxides should be removed by a chemical bath or mechanically with a fine emery after degreasing. Sandblasting, shotblasting or grinding with a fine wheel can be used to remove surface scale.

PART II—OPERATING CHARACTERISTICS AND USABILITY

BAlSi (Aluminum-Silicon) Classifications

Brazing filler metals of the BAlSi classifications are used for joining the following grades of aluminum and aluminum alloys: 2S, 3S, 4S, B50S, J51S, 53S, 61S, 62S, 63S and cast alloys A612 and C612. The *BAlSi-1*, *-2*, and *-3* filler metals are most suitable for brazing with the furnance and dip processes; the *BAlSi-4* is most suitable for the torch brazing process, but can be used with the furnance and dip processes. These filler metals are also used to a limited extent with other brazing processes. They are generally used with lap-type rather than butt-type joints.

Clearances of 0.006 to 0.010 in. are common for laps less than 1/4 in. long; clearances up to 0.025 are used for longer laps. Fluxing is essential for all processes. After brazing, the brazed parts must be cleaned thoroughly. Immersion in boiling water generally will remove the residue; if this is not adequate the parts are usually immersed in a concentrated nitric acid solution and then rinsed thoroughly.

BAlSi-1 brazing filler metal is a general purpose metal.

BAlSi-2 brazing filler metal is available only as coating on 3S and J51S aluminum alloy core sheet, coated on one or both sides.

BAlSi-3 brazing filler metal is a general purpose metal.

BAlSi-4 brazing filler metal is a general purpose metal used in some cases for its relatively high corrosion-resistant properties.

BCuP (Copper-Phosphorus) Classifications

Brazing filler metal of the BCuP classifications are used primarily for joining copper and copper alloys

with some limited use on silver, tungsten and molybdenum. Because of the phosphorus content, these filler metals should not be used on ferrous metals. Their use of alloys containing more than 10% nickel should also be avoided for the same reason. They are suitable for all brazing processes. Lap- and tee-type joints are generally used. These filler metals have self-fluxing properties when used on copper; however, a flux is recommended when used on all other metals, including the copper alloys. Joints made with these filler metals on copper have excellent electrical and thermal conductivities. Corrosion resistance is generally equal to or better than that of the base metal joined; however, they are not recommended for use in sulfurous atmospheres above room temperature.

These filler metals also have a tendency to liquate if heated slowly. It is important , therefore, especially if the filler metal is preplaced, to heat as rapidly possible. The color after brazing is light gray. Immersion in 10% sulfuric acid will restore the copper color.

It will be noted in Table A that the brazing temperature ranges begin below the liquidus. It is a basic principle in brazing that the lowest temperature within the recommended range be used, consistent with the joint clearance and the time needed to complete the braze. This in turn will depend on (1) the materials joined, (2) the brazing process employed and (3) the joint design used.

BCuP-1 brazing filler metal is used primarily for preplacing in the joint and is suited particularly for resistance brazing and some furnace brazing applications. This filler metal is somewhat more ductile than the other BCuP filler metals containing more phosphorus. It is also less fluid at brazing temperature. Joint clearances should be from 0.002 to 0.005 in.

BCuP-2 filler metal is extremely fluid at brazing temperatures and will penetrate joints with very little clearance. Best results are obtained with clearances of 0.001 to 0.003 in.

BCuP-3 filler metal is also extremely fluid at brazing temperatures. Joint clearances of 0.002 to 0.005 in. are recommended.

BCuP-4 filler metal is best used with joint clearances of 0.001 to 0.003 in.

BCuP-5 filler metal is particularly suitable for use where very close fits cannot be held. Joint clearances of 0.003 to 0.005 in. are recommended.

BAg (Silver) Classifications

Brazing filler metals of the BAg classifications are used for joining all ferrous and nonferrous metals except aluminum, magnesium, titanium and some other metals melting below 1500° F. There are many applications where these filler metals are used in the refrigeration and electrical equipment fields; the metals are also much used in making automobiles, some household goods, and plumbing and heating fixtures. They are used with all brazing processes. They are generally

Table A—Solidus, Liquidus and Brazing Range Temperatures

AWS-ASTM classification	*Solidus, ° F.*	*Liquidus, ° F.*	*Brazing temperature Range, ° F.*
Aluminum-silicon			
BAlSi-1	1070	1165	1150–1185
BAlSi-2	1070	1135	1120–1140
BAlSi-3	970	1085	1060–1185
BAlSi-4	1070	1080	1090–1185
Copper-phosphorus			
BCuP-1	1305	1650	1450–1700
BCuP-2	1305	1485	1350–1550
BCuP-3	1195	1500	1300–1550
BCuP-4	1185	1380	1300–1500
BCuP-5	1185	1500	1300–1500
Silver			
BAg-1	1125	1145	1145–1400
BAg-2	1125	1295	1295–1550
BAg-3	1195	1270	1270–1500
BAg-4	1240	1435	1435–1650
BAg-5	1250	1370	1370–1550
BAg-6	1270	1425	1425–1600
BAg-7	1145	1205	1205–1400
BAg-8	1435	1435	1435–1650
BAg-9	1280	1325	1325–1550
BAg-10	1335	1390	1390–1600
BAg-11	1365	1450	1450–1650
Copper-gold			
BCuAu-1	1755	1815	1815–2000
BCuAu-2	1620	1630	1630–1850
Copper and copper-zinc			
BCu	1980	1980	2000–2100
BCuZn-1	1650	1660	1670–1750
BCuZn-2	1630	1650	1670–1750
BCuZn-3	1590	1630	1670–1750
BCuZn-4	1570	1595	1600–1700
BCuZn-5	1585	1610	1620–1700
BCuZn-6	1690	1715	1720–1800
BCuZn-7	1685	1740	1690–1800
Magnesium			
BMg	770	1110	1120–1160
Heat resistant			
BNiCr	1850	1950	2000–2150
BAgMn	1760	1780	1780–2100

rapid melting and free flowing. Since they are so easily formed, they are available in various convenient forms for preplacing in a joint to be brazed. Lap-type joints are recommended but butt-type joints may be used if requirements are less stringent. Clearances should be between 0.002 to 0.005 in. for proper capillary attraction. Flux is generally required; however, if brazing is done in a vacuum or an inert atmosphere flux is not needed. This latter is the case, for instance, when using BAg-6 filler metal for brazing electron tubes.

BAg-1 brazing filler metal is free flowing and also has other qualities making it well suited for general purpose work. Its melting range is very narrow. The color after brazing is light yellow.

BAg-2 filler metal is, like BAg-1, free flowing and suited for general purpose work. Its broader melting range is helpful where clearances are not uniform, but, unless heating is rapid, care must be taken that the lower melting constituents do not separate out by liquation. The color after brazing is a light yellow.

BAg-3 filler metal is used primarily for joining carbide tool tips to tool shanks, as it wets the carbide well. It has a wide melting range in which solid and liquid do not tend to separate excessively. This makes it a good metal for bridging gaps or forming fillets. It

has generally good corrosion resistant properties but is not free-flowing to the degree BAg-1 and -2 are. Color after brazing is whitish yellow.

BAg-4 filler metal is, like BAg-3, used extensively for carbide tip brazing. It is freer flowing than BAg-3. The color after brazing is light yellow.

BAg-5 and *-6* filler metals are used particularly for brazing in the electrical industry. They are also used in the dairy and food industries where the use of cadmium-containing alloys might be prohibited.

BAg-7 filler metal is a general-purpose, low-melting metal used particularly for furnance brazing. Its whitish color after brazing makes it suitable for joining whitish metals like stainless steel. It is much used by the dairy and food industries.

BAg-8 filler metal is used primarily in the assembling of electronic and vacuum tubes. The metal is generally free flowing. However, it does not flow well on ferrous metals. The color after brazing is white.

BAg-9, *-10* and *-11* filler metals are used particularly for joining sterling silver. These three metals have different brazing temperatures and so can be used for step brazing of consecutive joints. The color after brazing is whitish.

BCuAu (Copper-Gold) Classifications

Brazing filler metals of the BCuAu classifications are primarily used for joining parts in electron tube assemblies where gaseous inclusions are particularly undesirable. Their low vapor pressures make them particularly suited for this work. In electron tube applications these filler metals are usually applied by induction, furnance or resistance brazing in a reducing atmosphere or in a vacuum and with no flux. For other applications, a borax-boric acid flux is used. The two BCuAu filler metals permit variation in brazing temperature so that step brazing can be used.

BCu and BCuZn (Copper and Copper-Zinc) Classification

Brazing filler metals of the BCu and BCuZn classifications are used for joining various ferrous and nonferrous metals. They can also be used with various brazing processes. Lap- and butt-type joints are commonly used.

BCu brazing filler metal is used for joining ferrous metals, nickel and copper-nickel alloys. It is very free-flowing. It is much used in furnace brazing, using a hydrogen or dissociated ammonia atmosphere and generally no flux. On metals that have constituents with difficult to reduce oxides (chromium, manganese, silicon, titanium, vanadium, aluminum, zinc), however, a flux may be required.

BCuZn-1, *-2*, *-3*, *-4* and *-5* brazing filler metals are used on steels, copper, copper alloys, nickel, nickel alloys and stainless steel. They are used with the torch, furnace and induction processes. Fluxing is required. A borax-boric acid flux is common. Joint clearances from 0.002 to 0.005 in. are suitable. With the BCuZn filler metals, overheating must be guarded against since voids may be formed in the joint by entrapped zinc vapors. Corrosion resistance of BCuZn filler metals is generally inadequate for joining copper, silicon-bronze, copper-nickel, or stainless steel base metals.

BCuZn-6 and *-7* brazing filler metals (called white brasses; formerly called nickel silvers) are used with steels, nickel and nickel alloys. They can be used with all brazing processes.

BMg (Magnesium) Classification

Brazing filler metal of the BMg classification is used for joining M1 magnesium base metal. It is used most with the torch, furnace and dip brazing processes and also somewhat with the other brazing processes, except resistance. Heating must be closely controlled to prevent melting of the base metal. Lap- and tee-type joints are most common. A flux is required with all processes. Clearances from 0.004 to 0.010 are best for most applications. Corrosion resistance is good, if the flux is removed after brazing. For furnace brazing, this filler metal is supplied with a small amount of beryllium which prevents possible ignition. For other brazing processes that addition is not required.

BNiCr and BAgMn (Heat-Resistant) Classifications

Brazing filler metal of the *BNiCr* heat-resistant classification is used chiefly for joining stainless steels and high nickel alloys to be used at elevated temperatures, as in jet engines. It also can be used on carbon and low-alloy steels. BNiCr filler metal retains its heat-resistant properties at temperatures up to 2000° F. It has excellent corrosion-resistant properties, also. It is used primarily for brazing in a controlled dry hydrogen atmosphere furnace, where no flux is required. It can be used in a controlled standard atmosphere furnace but then flux is required.

Brazing filler metal of the *BAgMn* heat-resistant classification is used chiefly to join stainless steel and high nickel alloys. It does not have the high temperature strength of the BNiCr but has good strength in the 500 to 900° F. range. Furnace brazing with a reducing atmosphere is most commonly used. Other brazing processes can be used. However, these processes require a flux and results are usually not as satisfactory.

Design Properties of Brazed Joints for High-Temperature Applications

With a reducing atmosphere and the use of a nickel-chromium base alloy using suitable procedures and equipment the successfully brazing of stainless steel for high-temperature work can be successfully accomplished

by Robert L. Peaslee and Willard M. Boam

DESIGNERS and fabricators of stainless steel assemblies have for years watched with envious eyes the progress made in copper brazing plain carbon and low-alloy steels. The many advantages of brazing have been denied users of stainless steel for the want of three things; a suitable furnace, a good stainless brazing alloy and a brazing technique which would produce satisfactory joints with such an alloy.

The standard copper brazing furnace causes any steel alloy containing 0.5% or more chromium to form a nonreducible chromium oxide which prevents successful brazing. As stainless steels have a high chromium content, this is a major obstacle. It can be overcome to a limited degree by the use of flux to protect the stainless alloy against oxidation. The resultant joint, however, is of erratic uniformity and strength. A reducing atmosphere such as that described in this paper is essential to produce high-quality joints.

With a reducing atmosphere, copper can be used as a brazing material, but only where the brazed assembly will operate under nonoxidizing conditions below 900° F. To fully utilize brazing technique in working with stainless steels, a brazing alloy is needed that will match more closely the physical properties of the stainless steels themselves. An alloy possessing such characteristics had been available for many years although its suitability for brazing had not been realized. The appreciation of the possibilities of this material led to the development by engineers of the Curtiss-Wright Corp., Wright Aeronautical Division, of a brazing technique which would produce the results which are discussed in this paper. A brief generalized statement of some of the details of the method is also given.

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THE BRAZING FURNACE

Stainless materials can be brazed without the use of flux by the dry hydrogen process. This process is not new, [1, 2] but its use has been limited. The dry hydrogen brazing process differs from the commercial hydrogen brazing process in that the hydrogen atmosphere must have a dew point in the vicinity of −40° F or below. It is not possible to maintain this low dew point in commercial furnaces which have standard door openings and ceramic brick linings. By using a sealed metal retort, very dry hydrogen and a few special precautions, an unusually low dew point can be readily maintained.

The furnace used for dry hydrogen brazing at the Wright Aeronautical Division is a double-ended GE electric furnace having a 2300° F maximum operating temperature. (See Fig. 1.) The center heating zone is equipped with molybdenum elements protected by a dissociated ammonia atmosphere. At both ends of the furnace there is a water-cooled antechamber which enables the load to be cooled rapidly under atmosphere.

The dry hydrogen is specially prepared by passing bottled hydrogen through a palladium catalyst tower which combines with any trace of oxygen to form water. The hydrogen then goes through an activated alumina drying column which removes essentially all the water. The gas (now having a dew point of −80 to −100° F) is routed to the brazing retort. The retort used with this furnace has a bottom tray equipped with gas inlet and outlet pipes and a thermocouple tube. The top of the retort fits into a U-shaped trough

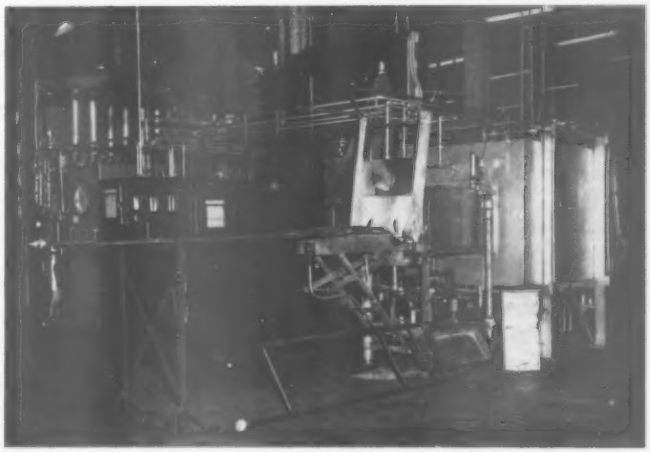


Fig. 1 Furnace used for dry hydrogen brazing

around the bottom tray, and the joint is sealed with alumina sand. The working space in this retort is 10 x 10 x 30 in. To maintain a dry atmosphere in the retort the hydrogen flowout through the sand seal must exceed the back flow of the moist room air attempting to enter the retort. The flow of hydrogen used in this application is 60 to 80 cfh.

A typical brazing cycle for this furnace is:

5-min purge with nitrogen.
10-min purge with dry hydrogen.
20 min to temperature.
30 min at heat.
90 min cooling time.
5-min purge with nitrogen.

Many other types of equipment can and are being used for dry hydrogen brazing and processing of stainless alloys. Besides the modified box-type furnace described above, the following standard types of furnaces can also be used: Standard box furnaces, pit-type gas or electric furnaces, tube furnaces, car furnaces, etc. While conveyor furnaces can be used for some heat processing of stainless alloys, to the authors knowledge, these furnaces are not suitable for use with the stainless steel brazing alloy dealt with here.

THE BRAZING ALLOY

A good brazing alloy must satisfy the most stringent demands that designers of stainless steel apparatus can make. Such a demand comes from the turbine design engineer. Metals used in the hot gas stream of gas turbines must operate for long periods of time in an oxidizing atmosphere, at temperatures from 1200 to 1800° F. A good brazed joint, then, must have suitable strength through at least 2000° F, so that accidental overtemperature operation will not result in complete joint failure.

The most common brazing alloy having a high melting temperature is copper. Copper, however, does not have suitable corrosion and oxidation resistance and its strength drops off rapidly with increasing temperature. During the last war the Germans developed an 85% silver, 15% manganese brazing alloy for use in attaching turbine blades to rotor disks. Investigation of this alloy showed that it was much harder to handle than copper and the tensile properties were below those of copper. The melting temperature of 1760° F was also found to be detrimental because it was too close to operating temperatures.

In searching for a suitable brazing alloy a few years ago, materials such as gold and its alloys, Monel and palladium alloys were under consideration. One material that was given serious consideration was a nickel-chromium base alloy having a solidus temperature of 1850° F and a flow point of around 1950° F. This alloy presented new problems in brazing since it could be procured only in powder form or as cast bars having a high hardness. Preliminary investigation of the alloy, however, showed such gratifying results that an extensive program was undertaken to develop a method by which it could be used for brazing and to compare it with copper and the silver-manganese brazing alloy.

The first method of applying this alloy (which, in the more finely powdered form such as was employed by Wright in the development, has been given the trade name of "Nicrobraz"*) to the joint was as a flux-powder paste, brazed without a protective atmosphere. The brazed joint was suitably strong, but had the entrapped flux pockets which are always associated with flux brazing. These flux inclusions were responsible for generally low and erratic joint strengths.

The use of dry hydrogen brazing eliminated this difficulty, as Nicrobraz was found to flow and braze very well in the dry hydrogen atmosphere. However, the composition of the alloy is such that solution with most stainless alloys is very rapid and it has been found advisable to use the highest brazing temperature possible. This procedure aids in obtaining a complete joint coverage before the brazing alloy has dissolved enough base metal to raise its melting point to the extent that high viscosity and freezing results.

BASE METALS

It was soon found that alloys containing % titanium were difficult to braze in pure dry hydrogen and this difficulty increased with the higher titanium contents. Alloys containing substantial amounts of aluminum also showed poor brazing and wetting characteristics in the dry hydrogen atmosphere. Fortunately, AISI 321, having about 0.5% titanium, shows good wetting and brazing qualities.

The principal high-temperature alloy used in this evaluation was S-590 (AMS 5770). (See Table 1.) This alloy is particularly adaptable to fabrication of highly stressed parts operating at 1200 to 1600° F, because it has suitable high-temperature physical properties and can be forged or rolled into sheet form. N-155 (AMS 5768) base material was used in a few instances to expedite procurement. This change did not introduce any new variables since S-590 and N-155 have nearly identical short-time physical properties and their chemical compositions are also similar.

AISI 347 stainless steel (AMS 5646) was selected as the base metal to be investigated for the class of parts where materials are only lightly loaded and where fair oxidation resistance is required.

AISI 431 stainless steel (AMS 5628) was used to represent the hardenable stainless steels as a third class of base metals involved in the brazing investigation. This material has fair corrosion resistance and high-strength characteristics up to 900° F. Two hardness levels were investigated to ascertain the effect of hardness on butt-tensile and shear-brazed joints.

TEST SPECIMENS

In setting out to obtain data on the physical properties of brazing alloys, the question arises as to the proper method of supplying brazing alloy to the joint. If the joint is narrow this is very simple, but when the joint becomes $^{3}/_{16}$-in. square and the base materials have poor thermal conductivity, more difficulty is encountered. On the large joints where the brazing alloy is placed around the entire perimeter and no provisions are made for venting, the edges of the joint frequently braze, leaving a void in the center which is the last portion to come up to heat. The test specimen used for this investigation was designed to assure the best and most uniform brazed joint. Figure 2 shows the essential steps in the development of an internal feeding joint specimen used for the fabrication of standard ASTM ($^{1}/_{4}$-in. gage diameter) tensile bars and Charpy keyhole notch impact specimens. Zero clearance was obtained on all specimens fabricated in this manner by clamping the blocks together and tack welding these blocks at the four corners of the joint.

* This alloy was known for many years as Colmonoy No. 6 and the data sheets in this paper, having been prepared prior to the adoption of the new name, bear the Colmonoy No. 6 designation.

Table 1—Nominal Chemical Compositions

	C	*Mn*	*Si*	*Cr*	*Ni*	*Co*	*Mo*	*W*	*Cb*	*B*	*Ag*	*N₂*	*Fe*
AMS 5770 (S-590)	0.45	1.50	0.65	20.00	20.00	20.00	4.00	4.00	4.00	..	..	..	Bal.
AMS 5768 (N-155)	0.15	1.00	0.50	20.25	20.00	20.00	3.25	2.50	1.00	..	..	0.15	Bal.
AMS 5646 (AISI 347)	0.10	1.50	0.75	18.00	10.00	..	..	..	0.80	..	..	..	Bal.
AMS 5628 (AISI 431)	0.16	0.55	0.40	16.25	2.25	..	..	..	..	..	..	..	Bal.
Colmonoy No. 6	0.45	..	4.50	15.00	Bal.	..	..	..	..	3.75	..	..	4.00
Silver-manganese brazing alloy	..	15.0	..	..	..	..	..	..	..	..	85.0	..	..

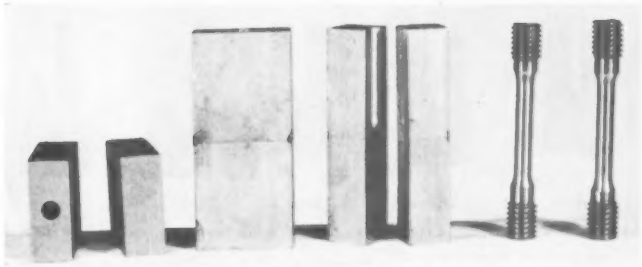


Fig. 2 The method of fabricating tensile (and impact) specimens used to obtain data on the physical properties of brazing alloys

A measured quantity of the Nicrobraz alloy (0.1 g) was placed in the feed hole and the blocks were brazed in pure dry hydrogen at 2150° F. The blocks brazed with oxygen-free copper wire were supplied with 1.7 g of alloy and brazed at 2050° F in dry hydrogen and the blocks brazed with 85% silver-15% manganese wire were supplied with 1.75 g of alloy and brazed at 2150° F in dry hydrogen. Heat treatment (including the brazing cycle) for each set of specimens is noted on the applicable physical property curves. Two tensile or impact specimens were cut from each block as indicated in Fig. 2.

The shear specimen used in this program was of the tongue and slot, double-shear type. (See Fig. 3.) This specimen was made from bar stock by first machining the tongue and slot ends and maintaining zero clearance or line contact. The specimen was then mounted in a V-block with the desired overlap and the powdered brazing alloy placed on top of each of the two joints and held in position by a drop of plastic cement. After brazing, the side faces of the joint were ground flat and the specimen threaded. One reason for using this type of specimen was that the fillets at either end of the joint could be removed, thereby eliminating any effect they might have had on the shear test results.

Fig. 3 Shear specimen

Since Nicrobraz had been found to dissolve and penetrate the base metal, it was desirable to determine the nature of this characteristic. It was believed that the amount of Nicrobraz alloy present and the length of time at the brazing temperature (2150° F) were the two factors controlling the degree of solution and penetration of the base metal. To evaluate these two factors, specimens of the type shown in Fig. 4 were used and the amount of Nicrobraz placed in the drilled hole of the specimen and the time held at 2150° F were varied. After each specimen received its prescribed cycle, the amount of base metal solution and extent of brazing alloy diffusion were measured on cross-sections of each specimen.

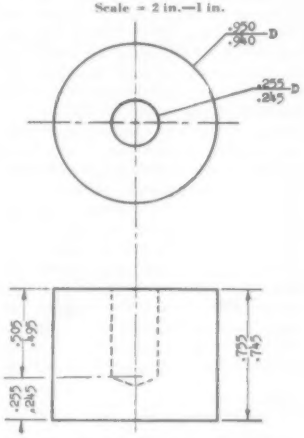


Fig. 4 Alloy penetration specimen

The high-temperature oxidation resistance of the Nicrobraz alloy, along with that of copper and silver-manganese, was not known. The test method devised, to obtain a numerical rating to show the effect of varying time in a high-temperature oxidizing atmosphere (air), employed a finished machined butt brazed, 1/4 in. diam, ASTM tensile specimen. The test was conducted by varying the length of time at a constant temperature for one set of specimens and then by varying the holding temperature for the second set while time at heat remained constant. After this treatment all specimens were tensile tested at room temperature. The effect of oxidation on their strength was clearly visible.

TENSILE PROPERTIES OF BRAZED JOINTS

The primary interest of this work was to obtain data for high-temperature applications, thus it will be noted that most of the data were obtained using S-590 (AMS 5770) as the base metal. Figures 5, 7–11 and 13 show graphically the results of tensile tests conducted from room temperature to 2000° F. The Nicrobraz butt brazed S-590 tensile properties compare very favorably with those of the base metal, from room temperature to 2000° F.

It may seem incongruous that the brazed tensile specimen and the base metal have nearly identical strength at 2000° F when the solidus temperature of Nicrobraz is only 1850° F. This can be readily understood when it is pointed out that the joint is no longer made up of the brazing alloy, but instead is a new alloy formed by the solution of the base metal and brazing alloy. This new joint material now possesses a melting temperature approaching that of the base metal and has good high-temperature properties and

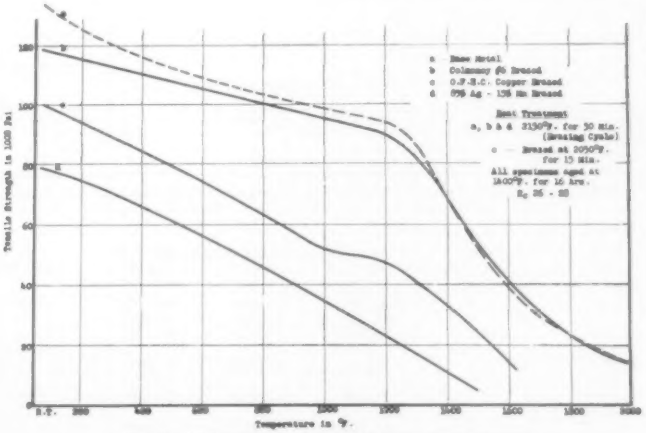

a Base Metal
b Colmonoy #6 Brazed
c O.F.H.C. Copper Brazed
d 85% Ag - 15% Mn Brazed
Heat Treatment
a, b & d 2150°F. for 30 Min. (Brazing Cycle)
c Brazed at 2050°F. for 15 Min.
All specimens aged at 1400°F. for 16 hrs.
Rc 35 - 38
Tensile Strength in 1000 Psi
Temperature in °F.
R.T.
1000
1500
2000

Fig. 5 Ultimate tensile strength vs. temperature

Butt brazed joint; AMS 5770 base metal

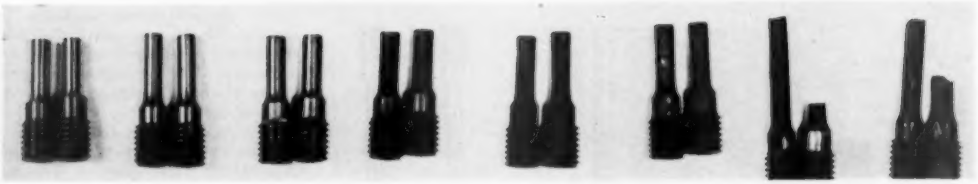


Fig. 6 Typical failures of nicrobraz brazed AMS 5770 (S-590) tensile specimens tested from room temperature to 2000° F

Specimens furnace brazed at 2150° F in dry hydrogen and aged 1400° F for 16 hr in air

generally improved oxidation resistance.

The data for the copper and silver-manganese butt brazed S-590 specimens show much lower room temperature tensile strengths, with the strengths dropping off with increasing temperature almost as a straight line to about 150° F below their melting temperature. The dip in the copper brazed specimen curve at 1000° F was unexpected, and at first thought to be incorrect, but the shear data for copper joints presented in Fig. 15 showed the same dip at this temperature and of slightly larger magnitude.

The butt tensile specimens brazed with copper and silver-manganese consistently failed through the brazed joint. The Nicrobraz specimens generally failed through the joint up to 1600° F, but above 1600° F, failures occurred both at the joint and in the parent metal. (See Fig. 6.)

The percent joint efficiency, Fig. 7, shows much more effectively the high-temperature properties of Nicrobraz as compared to the oxygen-free copper and silver-manganese alloys. Joint efficiency was calculated by taking the base metal ultimate tensile strength as 100% and comparing to it the ultimate tensile strength of the brazed specimens. The average strength of the Nicrobraz specimens at 1600° F was above the base metal strength, thus giving 106% joint efficiency.

Since we were primarily interested in the high-temperature brazing alloy, the high and low as well as the average ultimate tensile strengths have been tabulated in Table 2 for each test temperature. The total range of strength for the six brazed specimens at room temperature is 4000 psi as compared to 5400 psi for the four base metal tensile specimens. It is apparent that the strength variation in the brazed specimens is not a result of non-uniformity of the brazed joints, but simply a normal variation in tensile testing. Specimen-to-specimen uniformity at the other test temperatures also followed this same pattern.

The 0.2% offset yield strength and the proportional limit data for Nicrobraz butt brazed S-590, Fig. 8, also compare favorably with the base metal. However, they do not show the customary hump in the curve at the aging temperature of 1400° F. The elongation for the butt brazed S-590 tensile specimen, Fig. 9, is generally lower than the base metal elongation. This is particularly true at 1600° F where the base metal shows a sharp increase in ductility.

The ultimate tensile strength data, Fig. 10, also show that the Nicrobraz butt brazed properties of AISI 347 are very close to that of the base metal. The high

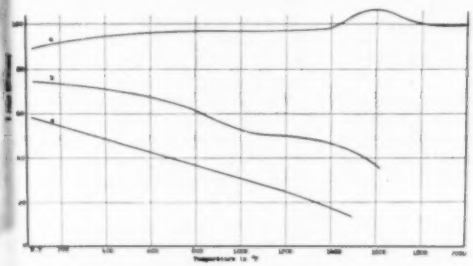


Fig. 7 Percent joint efficiency vs. temperature

Butt-brazed joint: AMS 5770 base metal. *a*, Nicrobraz brazed; *b*, copper brazed; *c*, 85% silver, 15% manganese brazed. Heat treatment: 2150° F for 30 min (brazing cycle); aged 1400° F for 16 hr; *R*., 26-28

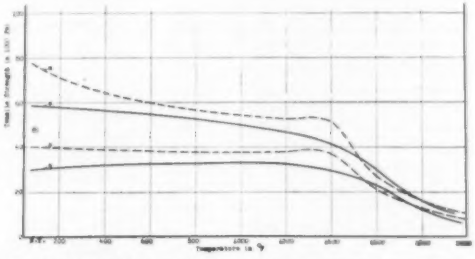


Fig. 8 0.2% offset yield strength and proportional limit vs. temperature

Butt-brazed joint: AMS 5770 base metal. *a*, 0.2% offset yield strength; *b*, proportional limit; ——, base metal; —— Nicrobraz brazed. Heat treatment: 2150° F for 30 min. (brazing cycle); aged at 1400° F for 16 hr; *R*., 26-28

Table 2—Ultimate Tensile Strength vs. Temperature Maximum and Minimum Strength Variation for Nicrobraz Brazed AMS 5770

Test temp., ° F	*No. of specimens*	*Colmonoy brazed strength, psi*			*No. of specimens*	*AMS 5770 base metal strength, psi*		
		Avg.	*High*	*Low*		*Avg.*	*High*	*Low*
R. T.*	6	119,230	121,500	117,500	4	134,500	137,000	131,600
800	4	100,150	102,200	98,000	3	103,230	106,800	98,700
1200	4	91,300	94,200	88,100	4	94,880	96,200	92,000
1400	2	69,250	70,000	68,500	2	70,850	72,700	69,000
1500	..	....	....	....	2	53,600	54,000	53,200
1600	4	41,730	44,700	40,300	5	39,280	43,200	33,800
1700	..	....	....	....	2	35,100	36,900	33,300
1800	4	23,280	25,800	22,200	4	23,680	24,200	23,200
1900	..	....	....	....	2	18,650	18,900	18,400
2000	3	13,790	14,420	13,320	2	13,810	14,020	13,600

* Room temperature.

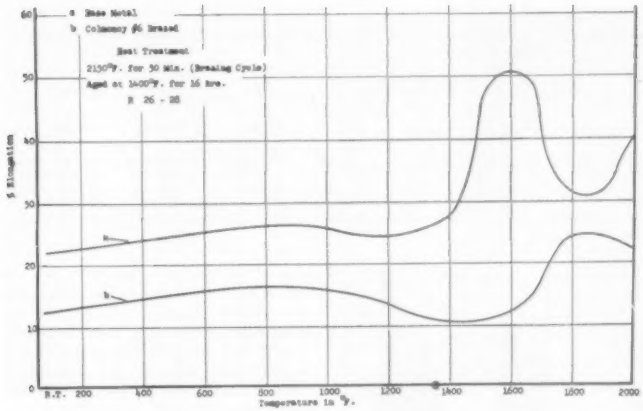


Fig. 9 Percent elongation vs. temperature

Butt-brazed joint; AMS 5770 base metal

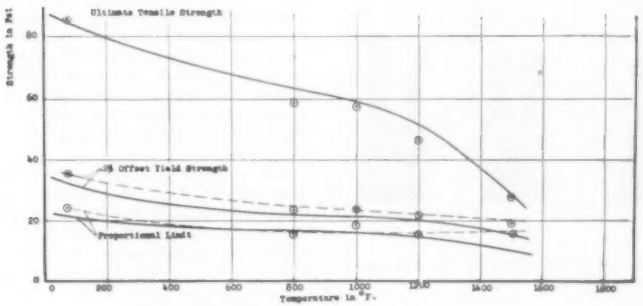


Fig. 10 Ultimate tensile strength vs. temperature

Butt-brazed joint; AMS 5646 base metal. ——, Base metal; ○, Nicrobraz brazed. Heat treatment: 2150° F for 30 min. (brazing cycle); R_c 74-76

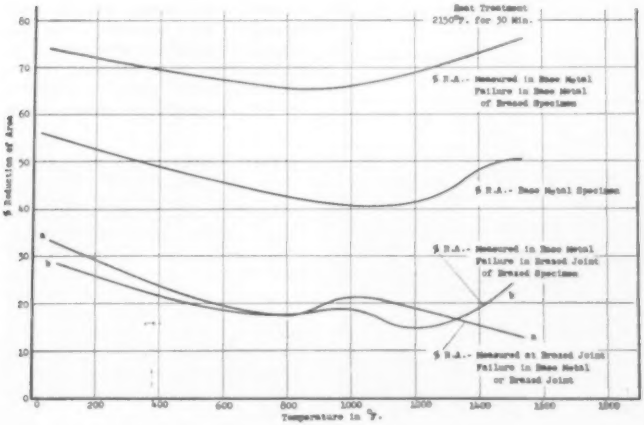

Heat Treatment
2150°F. for 30 Min.
% R.A.- Measured in Base Metal
Failure in Base Metal
of Brazed Specimen
% R.A.- Base Metal Specimen
% R.A.- Measured in Base Metal
Failure in Brazed Joint
of Brazed Specimen
% R.A.- Measured at Brazed Joint
Failure in Base Metal
or Brazed Joint
% Reduction of Area
Temperature in °F.

Fig. 11 Percent reduction of area vs. temperature

Nicrobraz butt-brazed joint; AMS 5646 base metal

and low values, as well as the average ultimate tensile strengths, for each test temperature are shown in Table 3. The data for the room temperature, 1200 and 1500° F points show very good uniformity and fit the base metal curve very well. The 0.2% offset yield strength and the proportional limit data for the Nicrobraz butt brazed specimen, also shown in Fig. 10, are found to be slightly higher than for the base metal.

The reduction of area data for the AISI 347 show best the tendency of Nicrobraz in a brazed joint to restrict the plastic flow of the base metal around it. Figure 11 shows that the reduction of area at the brazed joint is essentially the same regardless of the location of failure, whether at the joint or in the base metal. The base metal reduction of area, however, varies rather drastically with the location of failure. When the failure occurs at the brazed joint, the base metal reduction of area is similar to that at the brazed joint location, while failures in the base metal of a brazed specimen result in a much higher reduction of area—65 to 75% —in the base metal than that observed —40 to 55%— in an unbrazed metal specimen. The location of failure could not be related to any variation in tensile strength. Figure 12 shows typical tensile specimens that failed at the joint area and in the base metal. Two specimens pictured in Fig. 12, representing the 1500° F tensile test, clearly show the necking down on either side of the brazed joint while the joint area has relatively little reduction of area.

AISI 431 in a quenched and stress-relieved condition has a 190,000 psi ultimate tensile strength and is best suited for operating temperatures up to about 850° F. This alloy was used to show the effect of two different hardness levels on the ultimate tensile strength of a Nicrobraz butt joint. Surprisingly, the brazed specimens showed almost the same tensile strength for the R_C 30 and R_C 40 hardness levels, Fig. 13. The exact reason for this behavior is not known, although the authors feel it is due to a combination of two factors. One is the lower ductility of the high-hardness base metal which results in poor load distribution at the brazed joint during tensile testing. The other, and probably the more important, factor is the relatively low strength of the resulting alloy in the brazed joint, formed by solution of the AISI 431 base metal with the Nicrobraz. Thus, higher hardness of the base metal produces no increase in the brazed specimen strength.

The location of failures in the brazed AISI 431 tensile specimens of both hardness levels was through the joint area. The 0.2% offset yield strength and proportional limit data were not obtained on the brazed AISI 431 specimens. However, on all past data it has been found that when the ultimate tensile strength of

Table 3—Ultimate Tensile Strength vs. Temperature Maximum and Minimum Strength Variation of Nicrobraz Brazed AMS 5646

Test temp., °F.	No. of specimens	Colmonoy brazed strength, psi — Avg.	High	Low	No. of specimens	AMS 5646 base metal strength, psi — Avg.	High	Low
R. T.	16	85,160	89,800	80,660	4	84,930	88,900	80,600
800	6	58,750	62,600	53,100	3	63,070	63,600	62,400
1000	3	57,100	58,200	55,500	3	59,100	60,100	58,400
1200	6	46,420	50,000	42,000	3	51,670	52,600	51,000
1500	6	28,450	29,600	27,300	3	27,900	28,700	27,100

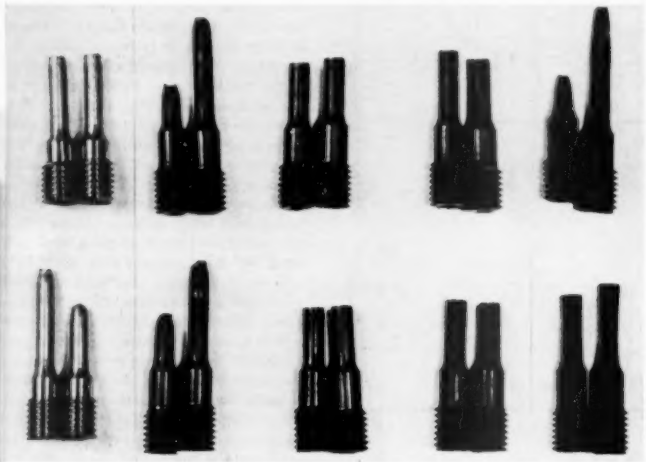


Fig. 12 Typical failures of Nicrobraz brazed AMS 5646 (AISI 347) tensile specimens tested from room temperature to 1500° F.

Specimens furnace brazed at 2150° F in dry hydrogen

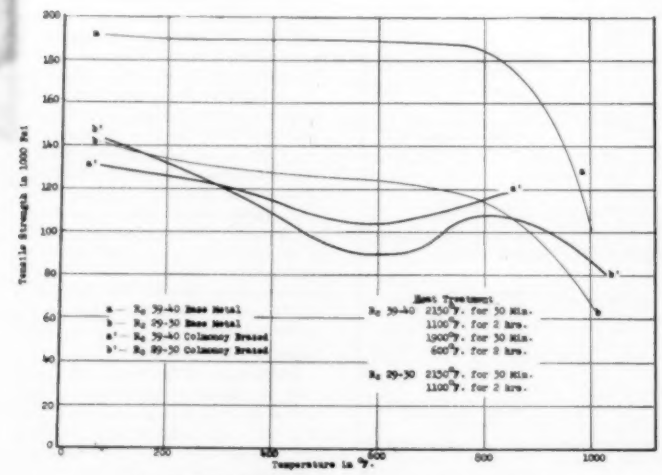

Tensile Strength in 1000 Psi
Temperature in °F.
a — Rc 39-40 Base Metal
b — Rc 29-30 Base Metal
a' — Rc 39-40 Colmonoy Brazed
b' — Rc 29-30 Colmonoy Brazed
Heat Treatment
Rc 39-40 2150°F. for 30 Min.
1100°F. for 2 hrs.
1900°F. for 30 Min.
600°F. for 2 hrs.
Rc 29-30 2150°F. for 30 Min.
1100°F. for 2 hrs.

Fig. 13 Ultimate tensile strength vs. temperature

Butt-brazed joint: AMS 5628 base metal

the brazed specimen is above the base metal, the 0.2% offset yield strength and proportional limit of Nicrobraz specimens follow very closely those of the base metal. Since the AISI 431 base metal has a high yield strength and proportional limit, the Nicrobraz specimen would probably have its yield strength and proportional limit about 5000 to 10,000 psi below those of the base metal.

The question arises as to exact location of failures that occur in the brazed joint area. For this information a Nicrobraz brazed S-590 tensile specimen, fractured at room temperature, was cross-sectioned along the axis of the specimen and a microspecimen prepared. A similar microspecimen was also prepared from an as-brazed solution-treated tensile specimen. Figure 14 shows photomicrograph of the two specimens.

The apparent joint thickness of the as-brazed specimens measures 0.002 in. thick and is surrounded by large columnar grains resulting from the brazing alloy diffusion in the base metal. The photomicrograph of the fully aged and tensile tested specimen shows a brazed joint width of 0.0015 in. surrounded by a narrow band of small grains. The brazing alloy diffusion has increased in depth and is now only discernible as partially formed grain boundaries. The tensile failure, although appearing to the unaided eye as a braze joint failure, actually failed through the grain boundaries of the band of readily discernible grains 0.002 to 0.004 in. away from the brazed joint. It was interesting to note that there were very few voids observed in the microspecimens.

SHEAR STRENGTH PROPERTIES OF BRAZED JOINTS

The shear strength data of Nicrobraz brazed S-590, as measured by the double-shear specimen, are shown in Fig. 15. For comparison, the shear strength of oxygen-free copper and silver-manganese brazed S-590 (obtained with the same design shear specimen) are also shown. It can be seen that the Nicrobraz brazed shear strength holds up very well through 1600° F. Typical shear failures are shown in Fig. 16.

The oxygen-free copper and silver-manganese brazed shear specimens show a pattern similar to the tensile data with the

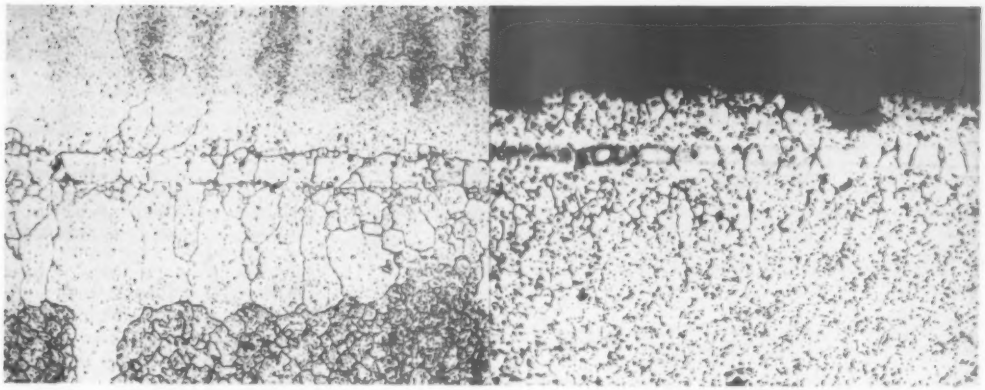


Fig. 14 (A) A photomicrograph of the joint area of a Nicrobraz brazed AMS 5770 tensile specimen

Brazing temperature, 2150° F; brazing time, 30 min; brazing atmosphere, dry hydrogen. Condition: Solution treated. Etchant: Marbles reagent. Magnification: 100 ×

Fig. 14 (B) A photomicrograph of the joint area of a Nicrobraz brazed AMS 5770 tensile specimen after test

Brazing temperature, 2150° F; brazing time, 30 min; brazing atmosphere, dry hydrogen. Condition: Solution treated and aged at 1400° F for 16 hr. Etchant: Electrolytic—10% hydrochloric in alcohol. Magnification: 100 ×

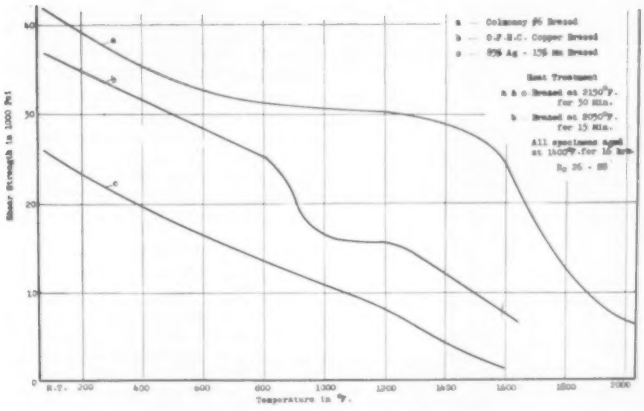
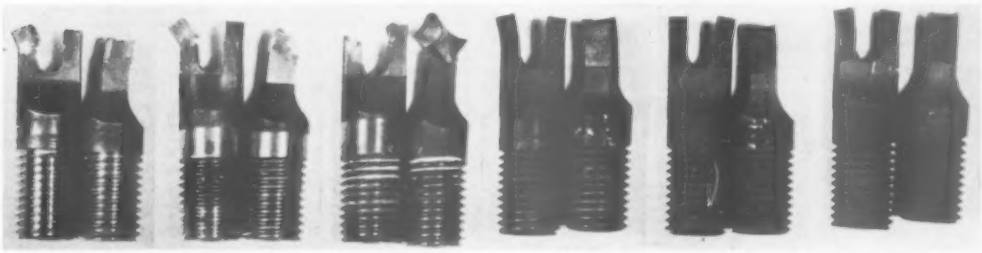


Fig. 15 Shear strength vs. temperature

Double shear joint; AMS 5770 base metal

room temperature shear strength being lower than that of the Nicrobraz specimen and dropping off in approximately a straight line which appears to be heading for zero strength at the melting temperature of each alloy. The curve for the oxygen-free copper brazed S-590 has a dip at 1000° F similar to that noted in the butt tensile strength data. The original curve was plotted, having data for three specimens each, at room temperature, 800, 1200, 1400 and 1600° F and showed a slight dip at 1200° F. Since it was felt this was abnormal, further data were obtained for the 1000° F point. These data showed very good uniformity but the dip in the curve was further accentuated as shown in Fig. 15.

A useful design tool that may be obtained from the data thus far is the ratio of shear strength to the ultimate tensile strength. Figure 17 shows, in phantom, a plot of the ultimate butt tensile strength



Room temp. 800° F 1200° F 1600° F 1800° F 2000° F

Fig. 16 Typical failures of Nicrobraz brazed AMS 5770 (S-590) shear specimens tested from room temperature to 2000° F.

Specimens furnace brazed at 2150° F in dry hydrogen and aged 1400° F for 16 hr in air

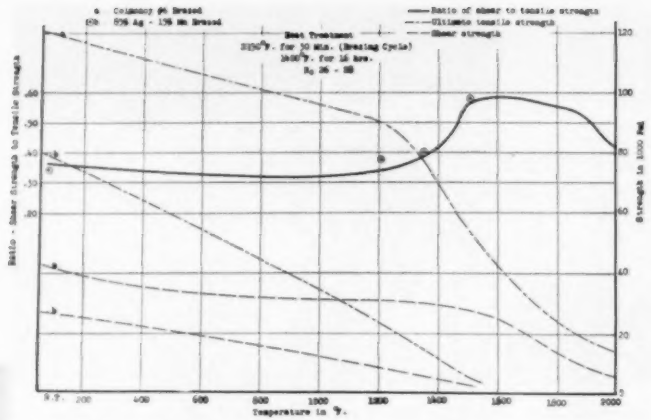


Fig. 17 Ratio of shear strength to ultimate tensile strength vs. temperature. AMS 5770 base metal

and the shear strength for Nicrobraz AMS 5770 data, as well as the plot for silver-manganese butt tensile and shear strength. From these two sets of curves the ratio of shear strength to butt tensile strength was plotted. It can be seen that this ratio is approximately 0.34 for temperatures from room temperature to 1200° F, then rises to 0.58 at 1600° F and gradually falls off again. One interesting point that these figures give is that the relatively hard Nicrobraz brazed joint and the soft silver-manganese brazed joint follow the same curve.

To evaluate the effect of base metal hardness on the shear strength of Nicrobraz joints, AISI 431 was again used at two hardness levels, Fig. 18. These data show that a higher shear strength could be obtained with this base metal but it was found that up to 700° F the specimens having the higher hardness level (R_C 40) had lower shear strength than specimens of R_C 30 hardness level. The cause of this phenomena is considered to be the same as that discussed for the butt tensile data of the same material. All failures of the Nicrobraz shear specimens occurred through or in the vicinity of the joint.

IMPACT STRENGTH OF BRAZED JOINTS

The specimen used in this investigation was of the Charpy notch keyhole type having the brazed joint at right angles to the axis of the specimen and through the centerline of the hole. This specimen was used so that the base metal and the brazed joint would be given nearly equal stress for failure. The base metal curve shows the customary increase from 7 ft-lb at room temperature to 17 ft-lb at 1600° F. The brazed joint, on the other hand, is nearly a straight line from room temperature to 1600° F with the nicrobraz brazed

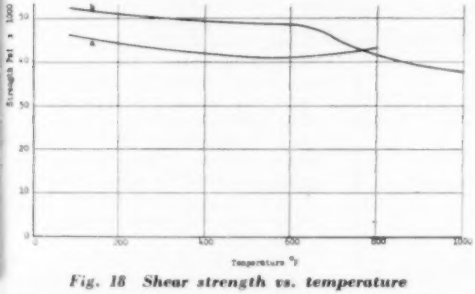


Fig. 18 Shear strength vs. temperature

Double shear joint; AMS 5628 base metal. Brazing alloy—Nicrobraz Heat treatment: *a*, 2150° F for 30 min brazing cycle; 640° F for 2 hr temper.; R_C 39–40. *b*, 2150° F for 30 min brazing cycle; tempered at 1100° F for 2 hrs; R_C 30–31

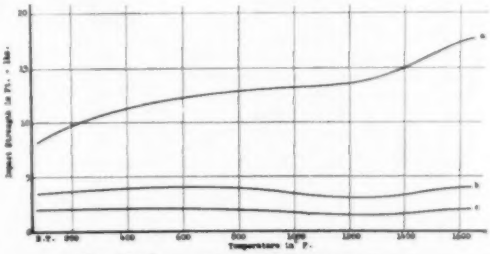


Fig. 19 Impact strength vs. temperature

Charpy notch key-hole specimen; AMS 5770 base metal. *a*, Base metal; *b*, Nicrobraz brazed; *c*, copper brazed. Heat treatment: 2150° F for 30 min (brazing cycle); aged at 1400° F for 16 hr

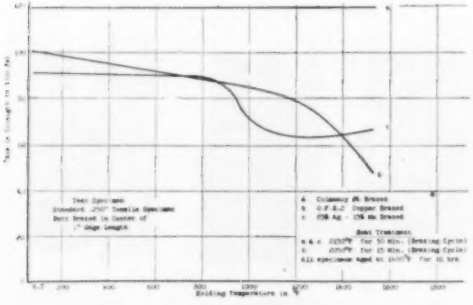


Fig. 20 Tensile strength vs. holding temperature

Holding time, 48 hr in still air; AMS 5770 base metal; tested at room temperature

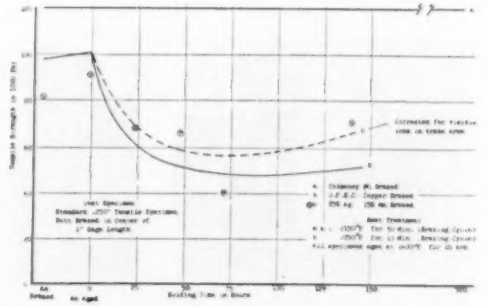


Fig. 21 Tensile strength vs. holding time at 1500° F in still air

AMS 5770 base metal; tested at room temperature

AMS 5770 having a strength of around 4 ft-lb, and the oxygen-free copper brazed joint having a strength of approximately 2 ft-lb. (See Fig. 19.)

OXIDATION PROPERTIES OF BRAZED JOINTS

The short time tensile properties of oxygen-free copper and silver-manganese were fair, but it is known that these materials have notably poor oxidation resistance at higher temperatures. To evaluate their oxidation resistance as well as that of Nicrobraz, a series of brazed standard 0.250 in. diam, 1-in. gage ASTM tensile specimens of S-590 were heated in still air for 48 hr at varying test temperatures. A second group of specimens were held at 1500° F for varying durations of time. All specimens were subsequently tensile tested at room temperature.

The first set of data, shown in Fig. 20, indicates that Nicrobraz joints are not affected by holding temperatures up to 1500° F. Since the oxidation resistance of this alloy is superior to that of the base metal, the authors feel that no adverse effect would be produced on the joint with holding temperatures up to 2000° F. The strength of the oxygen-free copper brazed S-590 was decreased by 20% after holding at 1200° F and 50% after holding at 1500° F. The silver-manganese brazed tensile specimens showed an approximate horizontal curve for two portions of the curve with a rapid drop in strength from 90,000 psi at 800° F holding temperature to 63,000 psi at 1200° F holding temperature.

The second set of data, shown in Fig. 21, indicates that a Nicrobrazed tensile specimen held at 1500° F up to 520 hr showed no adverse effect in room temperature properties. The oxygen-free copper brazed tensile specimens showed an increase in strength as a result of the aging heat treatment, but when subjected to treatment at 1500° F the room temperature strength dropped off rapidly with only 50% of its strength remaining after holding for 48 hr. When the fractured tensile specimens showed visible oxidation around the periphery of the joint, Fig. 22, the new area was calculated and the data plotted, Fig. 21.

The silver-manganese data were so spotty that no valid curve could be plotted, but the same general trend that existed for the copper-brazed joint is apparent. Both copper and silver-manganese curves picture a definite tendency of the alloys to show decreasing room temperature strength after only 48 hr at the holding temperature of 1500° F.

It should be noted that these data for copper and silver-manganese are only valid for classes of high-alloy materials having similar oxidation characteristics to that of the S-590 alloy. As a result of the high oxidation resistance of this base metal, all failures for the copper and silver-manganese brazing alloys occurred in the center of the brazing alloy joint. This mode of failure would not exist in low-alloy materials where failure would occur by the oxidation of the base metal.

STRESS RUPTURE PROPERTIES OF BRAZED JOINTS

The stress rupture properties of Nicrobraz butt brazed S-590 were determined at 1500° F. As may be noted in Fig. 23, the stress rupture life of the brazed S-590

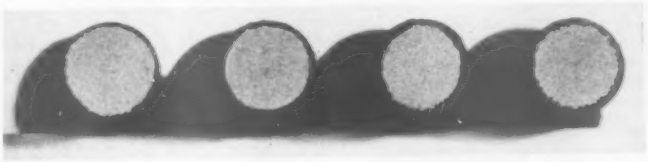


Fig. 22 Fractured tensile specimens showing physical oxidation around the periphery of the copper brazed joint

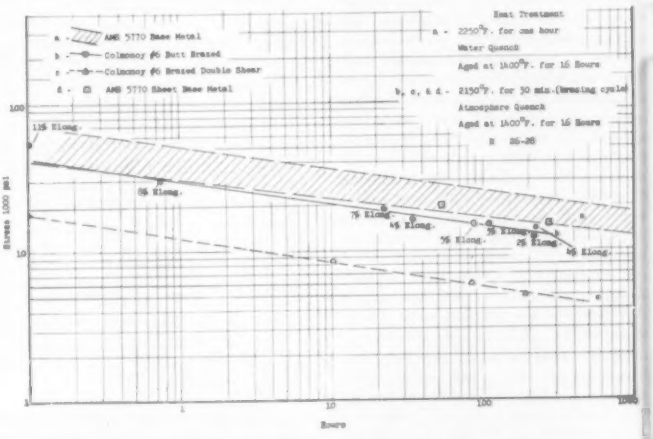


Fig. 23 Stress rupture data for Nicrobraz brazed AMS 5770 at 1500° F

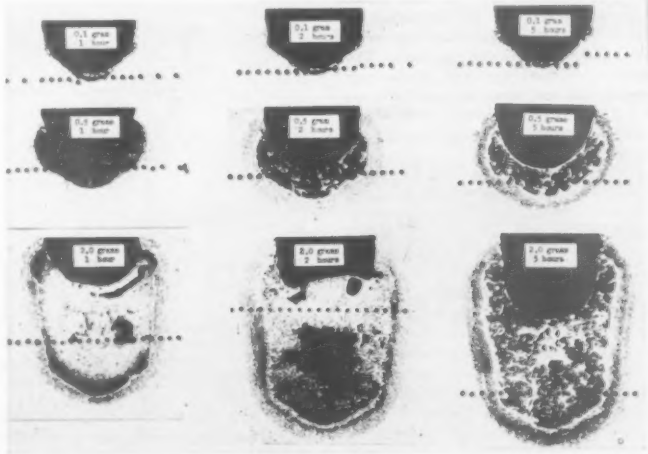

0.1 gram 1 hour
0.1 gram 2 hours
0.1 gram 5 hours
0.5 gram 1 hour
0.5 gram 2 hours
0.5 gram 5 hours
2.0 gram 1 hour
2.0 gram 2 hours
2.0 gram 5 hours

Fig. 24 Macrophotos of brazing alloy penetration samples as brazed at 2150° F with Nicrobraz, base metal is AMS 5768 (n-155). Magnification × 4

is lower than that of the base metal. The base metal band was obtained from previously published data* and is shown for comparison purposes. Base metal data were obtained from specimens quenched in water from 2250° F. The higher quenching temperature and more drastic quench produces higher rupture properties than a still air quench. Thus, the lower quenching temperature and the slower quenching rate of the brazed specimen is responsible for some lowering of the rupture strength.

BRAZING ALLOY CONTROL

Brazing alloys, such as copper and silver-manganese, show relatively little solution and penetration of the stainless steel base metal during brazing. Nicrobraz, on the other hand, is a low melting stainless alloy that very readily dissolves or penetrates the stainless steel base metal alloys. To obtain a numerical evaluation of the solution and penetration quality of Nicrobraz, the penetration specimen previously described was used. (See Fig. 4.) With the aid of this specimen the effect of the quantity of brazing alloy and time at heat were investigated. Figure 24 shows photomicrographs of the nine penetration specimens after they had been sectioned through the centerline of the 0.250-in. hole, polished and etched. At the top of each specimen can be seen the width of the 0.250-in. drilled hole, while at the lower portion the hole is noticeably enlarged due to melting of the base metal by the brazing alloy. The shaded area around the enlarged portion of the hole indicates the grain boundary penetration of the brazing alloy into the base metal. Figure 25 shows graphically the results obtained from these nine specimens. From these data it is observed that regardless of "holding" time at the brazing temperature, the penetration of the Nicrobraz into the stainless base metal takes place first, and at a rapid rate. The solution, or dissolving away, of the base metal does not occur appreciably until 0.5 g of alloy are reached. With added brazing alloy the base metal solution becomes quite rapid.

Considering the foregoing information, it is increasingly apparent that the quantity of Nicrobraz alloy at any one location must be kept to a minimum. It should also be noted that a small residue or skeleton is sometimes left when the lower melting constituents of the Nicrobraz alloy are pulled into the joint before melting is completed. The remaining residue as well as the joint material has changed in chemical composition to such an extent that a readily machinable material having a hardness of R_c 30 now exists. Figure 26 shows a hardness survey across the center specimen in Fig. 24 and is typical for as-brazed S-590 and Nicrobraz alloy.

* Data published by Allegheny-Ludlum.

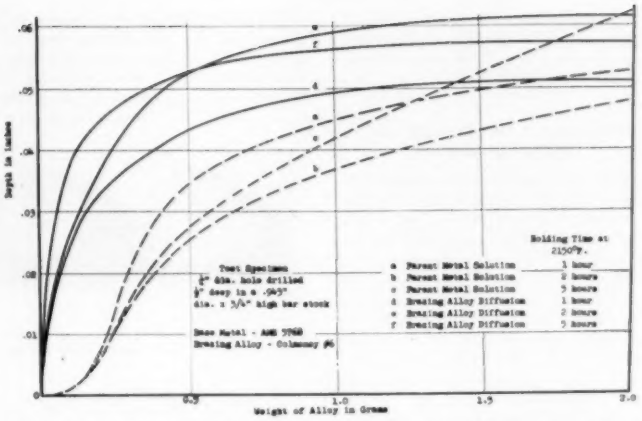

Depth in Inches
Weight of Alloy in Grams
Test Specimens
Base Metal - AMS 5768
Brazing Alloy - Colmonoy #6
Holding Time at 2150°F.
a Parent Metal Solution 1 hour
b Parent Metal Solution 2 hours
c Parent Metal Solution 5 hours
d Brazing Alloy Diffusion 1 hour
e Brazing Alloy Diffusion 2 hours
f Brazing Alloy Diffusion 5 hours

Fig. 25 Depth of base metal solution and brazing alloy diffusion vs. weight of Nicrobraz brazing alloy. AMS 5768 base metal

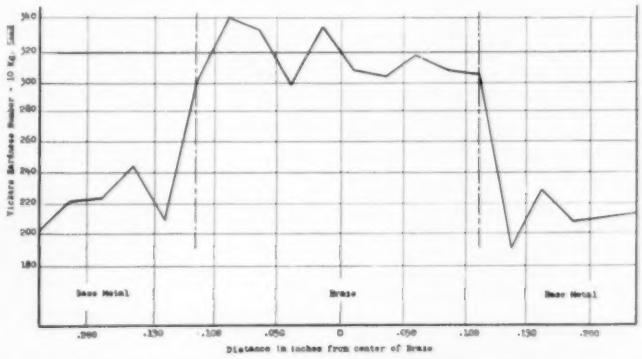


Fig. 26 Hardness survey of cross-sectioned alloy penetration specimen

AMS 5768 base metal, Nicrobraz brazing alloy. 0.5 gm Nircobraz held at 2150° F for 2 hr. Specimen No. 5

Fig. 27 Mercury control element AISI 347 stainless steel 0.032 in. tube and bulb. Five joints brazed in one operation with Nicrobraz

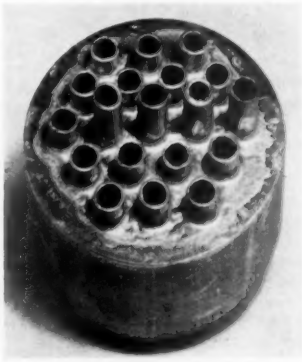


Fig. 28 Sample heat-exchanger specimen. AISI 347 stainless steel tubes and sheet. Brazed in one operation with Nicrobraz

Nicrobraz cannot be preformed for placement like soft wire alloys. It was, therefore, necessary to obtain a method of holding the powdered alloy in place, prior to brazing, without interfering with the

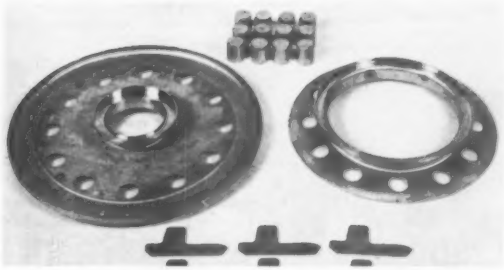


Fig. 29 Detail parts of a heat shield prior to brazing. All joints are brazed with Nicrobraz in one furnace operation

Fig. 30 Heat shield after brazing. Part is made of austenitic stainless steel and operates at about 1000° F

dry hydrogen atmosphere. One material that was found to be particularly suited for this purpose was an acrylic resin. This resin, thinned out and used in small quantities, does not interfere with the dry hydrogen brazing atmosphere. The most interesting feature of this resin was that it can hold the powdered alloy on the underside of a part all the way up to the brazing alloy melting temperature without dropping the smallest particle.

More recent developments have introduced Nicrobraz as plastic-bonded strip and wire, washers and special flat shapes. These forms are very useful in the metering of alloy in small openings and on very thin sheets of stainless. (See Figs. 27–30.)

Other methods now being used for application of Nicrobraz are the preforming, sintering and hot-metal spraying processes.

BRAZING OF TURBINE PARTS

One of the first turbine parts set up for dry hydrogen brazing was a stator shroud and blade assembly. This part, which is shown in Fig. 31, previously had precision cast Stellite 21 blades plug welded to a 35 nickel-15 chromium sand casting. The welding of this part caused about 0.070-in. distortion at the tips of the blades in spite of a heavy welding fixture. To meet the required blueprint tolerances of ±0.005 in. between the mounting flange and blade tips, it was necessary to go through an elaborate procedure for straightening the blades. At the time this assembly was set up for brazing, the silver-manganese alloy was being used. However, the noteworthy part of this illustration is that these parts came from the 2100° F brazing cycle well within the ±0.005 in. tolerance requirement between the flange and blade tips. This was, in part, due to the plain carbon shim stock clips on either end of the assembly that held the blades in position during loading and relaxed completely at the temperature where differential expansion would upset the blade alignment. The finished assemblies, brazed with silver-manganese in dry hydrogen and earlier assemblies brazed with Nicrobraz powder and flux, performed satisfactorily in engines with 1200 to 1400° F metal operating temperatures at the joint. (See Fig. 32.)

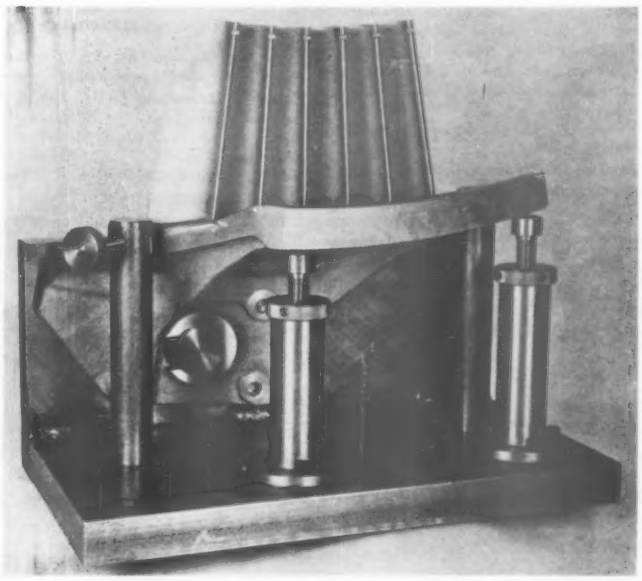


Fig. 31 Stator shroud and blade assembly set up for dry hydrogen brazing

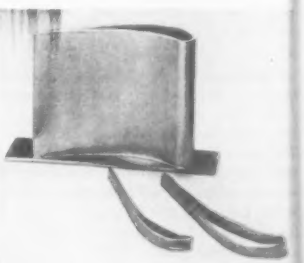


Fig. 32 Sample hollow turbine blade. Rolled stainless steel brazed to simulated butt section and brazed trailing edge, with Nicrobraz

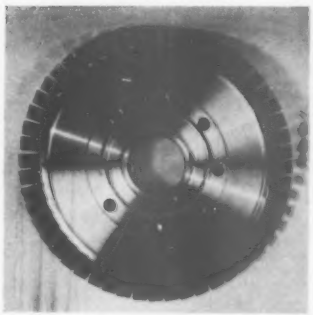


Fig. 33 Brazed compressor rotor wheel

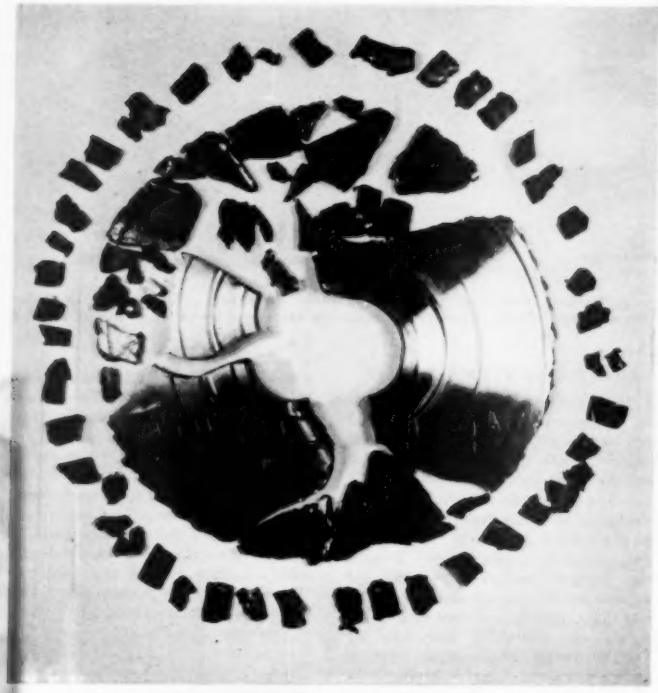


Fig. 34 Rotor wheel after whirl testing

Another type part that was stainless brazed in dry hydrogen was a compressor rotor wheel made of precision cast AISI 431 blades and an AISI 431 forged hub. The blade butts were fitted into slots in the periphery of the disk, the Nicrobraz was placed on the end of the joint and the wheel brazed in dry hydrogen. (See Fig. 33.) These wheels operated satisfactorily at their design speed of 12,000 rpm without difficulty.

To obtain a better picture of what the actual brazed part would withstand, one wheel was obtained and prepared for whirl testing. This testing was done at room temperature in an evacuated chamber and consisted of holding the part at the desired speed for 1 min. The wheel was whirled at 2000 rpm increments from 20,000 to 40,000 rpm and then in 1000 rpm increments with failure occurring at 41,800 rpm through the hub. (See Fig. 34.) There was no brazed joint failure. As an indication of the approximate load on the wheel, a stress analysis was made for the 40,000 rpm speed. The results indicated a tangential rim stress of 72,000 psi and a maximum tangential hub stress of 195,000 psi, a stress above the ultimate tensile strength of the base metal. These calculations did not take into consideration the redistribution of stresses when the hub passed its yield strength.

SUMMARY

1. Nicrobraz stainless brazing alloy, when used with the appropriate base metal and brazed (following proper techniques) in a dry hydrogen atmosphere, has satisfactory physical properties and oxidation resistance for high temperature applications through 2000° F.

2. Stainless steel parts are readily and economically fabricated by brazing with the Nicrobraz stainless alloy without scaling, appreciable distortion or internal stress which is generally associated with most welded assemblies.

3. Oxygen-free copper and 85% silver-15% manganese, as brazing alloys, do not have suitable physical properties or oxidation resistance for application at temperatures over 900° F.

4. The quantity of the Nicrobraz alloy must be critically controlled because base metal solution at the brazing temperature varies directly with the weight of stainless brazing alloy used and the time at heat. The weight of alloy is the more important variable.

5. Metals having high quantities of aluminum or titanium as alloying elements are difficult to braze in a dry hydrogen atmosphere.

6. Acrylic resins are a satisfactory binder for holding the powdered stainless brazing alloy in place before and during the brazing operation. The binder is best used in small quantities and does not interfere with the dry hydrogen atmosphere. Plastic bonded strip and wire are also important methods of applying the brazing alloy.

The discussion, "Brazing for High Temperature Service," which was given by R. L. Peaslee at the AWS Annual Meeting during the Metal Show at Detroit, Oct. 17, 1951, was an excerpt from this paper.

ACKNOWLEDGMENTS

The authors wish to thank Herman Hanink, Manager, Materials and Processes Research Division, for his help and guidance throughout this program, L. Glasier for the Materials Evaluation unit and other members of the Division who aided in preparation of these data.

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1951 Adams Lecture

The Welding of Copper by the Inert-Gas Metal-Arc Process

Smelting and refining of copper, properties, copper welding by other methods and complete information on the inert-gas metal-arc process of welding copper

by John J. Chyle

MR. PRESIDENT, MEMBERS OF THE AMERICAN WELDING SOCIETY, LADIES AND GENTLEMEN:

I deeply appreciate the honor of being chosen the ninth Comfort A. Adams Lecturer, and hope that the subject which I have prepared will measure up to the high standards established by my predecessors.

It has been my privilege to know Dr. Adams personally, and to know of his wide interest in the field of welding and electrical engineering. Dr. Adams is often referred to as the Father of the AMERICAN WELDING SOCIETY for the enthusiasm and zeal which he has shown in organizing this SOCIETY in its early days.

This evening the subject of my talk will be "The Welding of Copper by the Inert-Gas Metal-Arc Process." This subject is closely related to the activities which Dr. Adams was associated with through his life, namely electrical engineering. This subject is related, to a large extent, to the electrical industries, since the largest single use of copper is for electrical purposes in one form or another. Electrical engineering is the basis for many of the welding processes which have been developed, using the electrical energy as a source of heat. There is also wide interest in this subject because of the rather phenomenal development of the inert-gas metal-arc welding process in the last ten years, which has made the welding of copper by this process commercially practical. The methods and results which were obtained in the welding of copper by this process can also be used for the welding of other nonferrous metals, and they open the field to some of the new metals which have only recently been made available.

John J. Chyle is Director of Welding Research with the A. O. Smith Corp., Milwaukee, Wis.

Presented at the Thirty-Second Annual Meeting, AWS, Detroit, Mich., week of Oct. 15, 1951.

EARLY HISTORY OF THE DISCOVERY OF COPPER

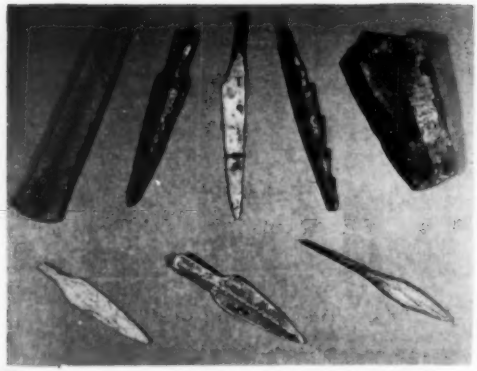
While copper was one of the first metals used by primitive man, with records of copper objects dating back to 5000 B.C., it is an interesting fact that only within the last decade has it been possible to obtain copper welds with characteristics similar to those of the parent metal.[1-3]

The first attempts by primitive man to use metals were confined to those metals which were found in nature in their relatively pure or metallic state. It is believed that gold was the first metal discovered by early man, since in its natural state gold is generally found untarnished, as a bright shiny yellow metal.[1-3] However, the occurrence of precious metals such as gold and silver was not too abundant, and for that reason they were not used to any great extent except for ornamental and ceremonial purposes.

The discovery of copper might have been accidental in the quest for stone implements. It was very probable that native copper was mistaken for stone, and since it happened to possess unusual qualities of ductility and malleability, the metal was worked rather easily with stone implements into useful objects.

The earliest records of copper implements trace back to the Chaldean excavations, dating to a period between 5000 to 4500 B.C.[1-3] On the American continent, the only known early copper objects to be found were those which were formed by the early American Indians. These objects were found in Wisconsin along the St. Lawrence River area, and were in the form of spears, hatchets, axes, hooks and ornamental pieces.[5]

Through the courtesy of the Milwaukee Public Museum, several illustrations were prepared showing some of the early American copper objects which were

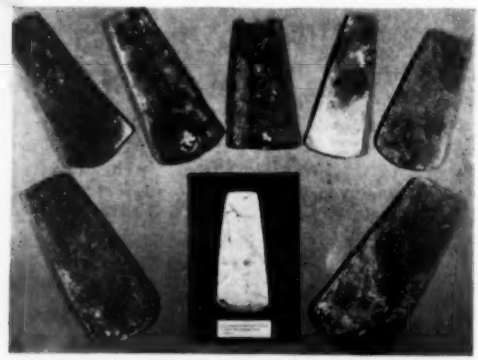


(Courtesy of the Milwaukee Public Museum)

Fig. 1 Varieties of archaic copper implements

formed at a time known as the Pre-Pottery Period, and are believed to be at least 3000 years old. Figure 1 shows the fine workmanship in forming the spears, knives and hooks. Figure 2 shows a collection of axes which were found, and also shows the excellent form of these tools. The center specimen was cleaned to reveal the bright copper metal below the outer corrosion coating.

Following the discovery of coppr by early man, the next logical development was in the melting of the natural occurring copper into useful objects. At about the same time, the art of smelting was also discovered, and the first evidence of copper smelting, as determined by objects which were found, indicates that this occurred in a period probably between 2500 to 2000 B.C.[1-3] In the development of the smelting of copper, special ores were found which imparted new properties to the copper, with the result that the smelting of bronze was developed at an early date. According to historians, the first bronze objects date back approximately to 2500 B.C.[1-3] The discovery of iron smelting occurred at a considerably later time, with



(Courtesy of the Milwaukee Public Museum)

Fig. 2 A group of archaic copper implements

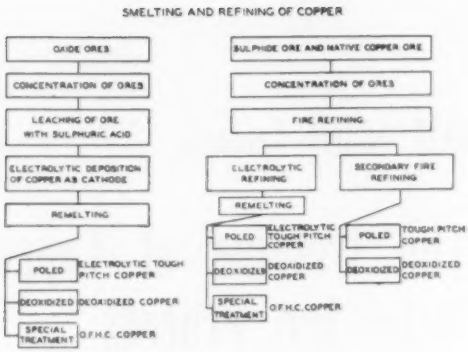


Fig. 3 Steps followed in the smelting and refining of copper

the first known iron objects produced by smelting the ore dating back to about 1350 B.C. at Gerar, Palestine.[1, 2, 3] Thus it can be seen that the transition from the Stone Age to the Metal Age was bridged first by the use of copper, then by bronze and later followed by iron.

SMELTING AND REFINING OF COPPER

In the smelting and refining of copper, the first step consists of concentrating the ore, and the important operations are shown in Fig. 3. The type of concentration depends to a large extent on the nature of the ore and usually consists of grinding and pulverizing the ore, followed by gravity concentration and oil flotation. The concentrates from native copper ores are then mixed with coke or coal screening and then refined in a reverberatory furnace. With sulphide ores, which are the source for the greatest production of copper in this country, the ore is concentrated by crushing and grinding, followed by oil flotation, and is then refined in converters and reverberatory furnaces.[7, 8]

In the case of some of the oxide types of ores, the ore is concentrated and the copper is leached out of the ore by treatment with sulfuric acid, and is then deposited as copper cathodes. This type of treatment is generally used in the processing of South American ores in Chile.[9]

In the refining of copper, two basic processes are used. These are fire refining and electrolytic refining. In the case of fire refining, the major impurities found in the copper ore are removed by oxidation. The impurities are either oxidized to form gases such as sulfur dioxide, or they are converted to oxides which are then slagged off with other impurities, and removed from the molten copper. Fire refining is generally the primary step in the production of copper from sulfide and native ores, and may then later be further refined by an additional fire remelting or by electrolytic refinement. In the electrolytic refinement of copper which is used for the bulk of the copper produced in

the country at the present time, this process is used because it either removes some of the precious metals which are found associated with the copper ore, and which generally pay for the cost of electrolytic refinement, or electrolytic treatment is used to remove objectionable impurities which cannot be completely removed by the fire refining method. Regardless of whether the copper is electrolytically refined or fire refined, the final stage in the production of the commercial grades of copper requires a final operation in which the copper is remelted for purposes of pouring or producing the requested fabricating shapes.

In the remelting operation the copper is processed by one of three methods. It may be poled to remove the excess oxygen to form tough pitch copper. It may be deoxidized with phosphorus or other deoxidizers to form deoxidized copper. Or it may be remelted under special conditions where the oxygen content is reduced to zero, for a grade known as OFHC, oxygen-free high conductivity.

To a certain extent, the smelting and refinement of copper is quite similar to that of iron and steel, in that the metallurgical operations consist of removal of impurities by oxidation. Since the copper is itself oxidized, it is then necessary to deoxidize the small amount of copper oxide, by a process called deoxidation. In the case of copper, this is most generally done by a process called poling, in which a green wood pole is immersed under the surface of the molten copper.[9] The action of poling is such that it produces a reducing condition, and the breakdown of the cellulose of the wood in the green pole results in the formation of hydrogen and carbon monoxide, which are very effective in reducing the cuprous oxide present.[10] The steps in the deoxidation of copper by poling are carefully controlled, and during the operation, test samples are removed from time to time to determine what degree of deoxidation is obtained.

Schematic sketches as shown in Fig. 4 illustrate the terms used in deoxidation of copper by poling, in which varying degrees of oxygen content remaining in the copper are termed as either low pitch or low set, tough pitch or level set, or high pitch copper.

The desired type of copper is obtained when a test casting, as shown in the middle sketch, has an oxygen content of 0.02 to 0.05% and is known as tough pitch copper. The term "pitch" or "set" refers to the appearance of the surface of the test casting, whether it is depressed or low pitch as shown in the lower figure, or level tough pitch or blistered high pitch as shown in the top figure. The bulk of copper produced and used today is classified as electrolytic tough pitch copper.

In deoxidized copper, the oxygen is most generally removed by phosphorus, using an alloy of copper and phosphorus. Copper may also be deoxided with other oxygen removers such as lithium, calcium, boron, aluminum and silicon. However, the most important deoxidizer is phosphorus, and when the general term "deoxidized copper" is used in this country, it refers

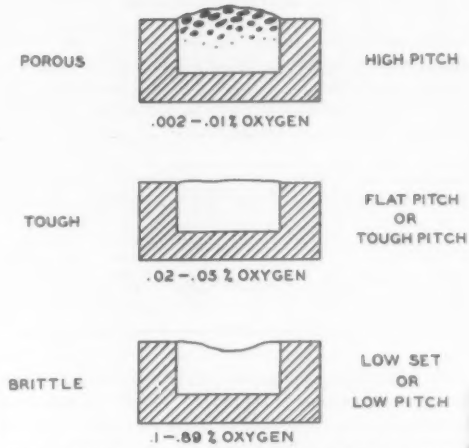


Fig. 4 Schematic presentation of the effect of residual oxygen on soundness of copper test castings

to phosphorous deoxidized copper having phosphorus within the limits of 0.015 to 0.04%.

The third grade of commercial copper which is produced only to a limited extent is known as oxygen-free high-conductivity copper (OFHC). In the production of this grade of copper, the last trace of copper oxide is removed by carbon and the process is so controlled that the molten copper is not exposed to contact with air. The oxygen-free high-conductivity copper is produced with practically zero content of oxygen and contains no alloying elements or metalloids as residual elements. The production of oxygen-free high-conductivity copper requires special equipment and therefore is used only to a limited extent, except where the particular purpose of this type of copper is needed.

The three groups of commercial coppers which will be considered are as follows: (1) Tough Pitch Copper, (2) Deoxidized Copper, (3) Oxygen-Free High-Conductivity Copper (OFHC).

Under each one of the three groups there may be additional subdivisions. In the Tough Pitch group these are the electrolytic, the fire refined, the silver bearing, the arsenical, the selenium, etc. In the group of Deoxidized Coppers we also have further subdivisions such as the high and low residual phosphorus, the silver bearing, the arsenical, etc. In the group of the Oxygen-Free High-Conductivity Copper we have the silver bearing, the tellurium bearing, the oxygen-free without residual deoxidants. However, we will consider only one grade in each of the three groups, referring only to the grade most commonly used in the industry.

For the tough pitch group only the electrolytic tough pitch grade will be considered. For the deoxidized group the high residual phosphorous grade will be considered. For the oxygen-free high-conductivity group only the oxygen-free high-conductivity copper without residuals will be considered.

MECHANICAL PROPERTIES OF COPPER

The mechanical properties for each of the three groups in the annealed condition which are typical are shown in Table 1. It can be observed that the mechanical properties at room temperature are nearly the same for all three groups.[10]

Table 1—Mechanical Properties of Wrought Coppers

Type of copper→	*Tough pitch*	*Deoxidized*	*Oxygen-free high conductivity*
Tensile strength, psi, annealed	31,000	30,000	30,000
Yield strength, psi, 0.2% offset	9000	8700	10,500
Elongation, % in 2 in.	57.8	53.4	56.3

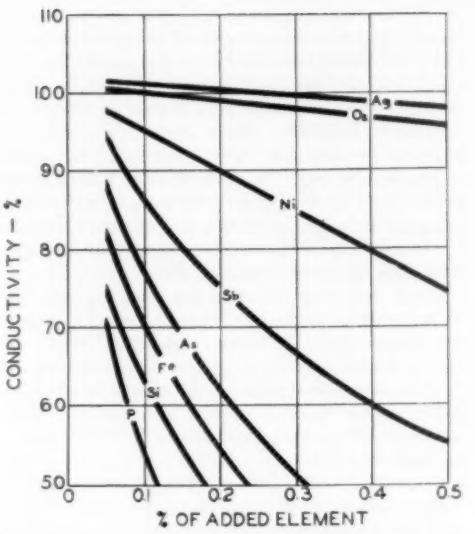
In Table 2 are shown some of the physical properties of annealed wrought coppers. It will be observed that the oxygen content of tough pitch copper is in the range of 0.02 to 0.08%, while for the deoxidized and OFHC grades, the oxygen content is nil. The phosphorous content is nil for the tough pitch and the oxygen-free grade. The phosphorus content for the deoxidized grade is in the range of 0.015 to 0.04%. The electrical conductivity for the tough pitch grade and the OFHC grade is alike, and is slightly above the 100% value of the International Annealed Copper Standard. The electrical conductivity for the deoxidized copper varies from 75 to 90%, depending largely upon the amount of phosphorus present. The thermal conductivity follows a pattern similar to the electrical conductivity as indicated.

Table 2—Physical Properties of Wrought Coppers

Type of copper→	*Tough pitch*	*Deoxidized*	*Oxygen-free high-conductivity*
Copper, %	99.9	99.9	99.96
Oxygen, %	0.02–0.08	None	None
Phosphorus, %	None	0.015–0.04	None
Electrical conductivity, % IACS at 68° F	101.6	75–90	102.0
Thermal conductivity, Btu per sq ft per ft per hr per ° F at 68° F	227	175–200	227

One of the most important properties of copper is its electrical conductivity. The conductivity of copper may be markedly affected by elements which are present as residuals, or are added purposely for specific properties. Phosphorus has a very powerful effect in reducing the electrical conductivity of copper as shown in Fig. 5. As little as 0.05% phosphorus reduced the electrical conductivity approximately 30%. The reduction in electrical conductivity is also markedly affected by such elements as silicon, iron, arsenic and antimony. Silver and oxygen in the amount indicated on the chart have slight effect on the electrical conductivity of copper.[11,12,13]

The effect of cold working on the electrical conductivity of copper is shown in Fig. 6. Severe cold reduction amounting to approximately 80% reduces the electrical conductivity by only 4%.[14]



20° C (68° F) (Owen W. Ellis)

Fig. 5 Approximate effects of various elements on the mass conductivity of copper

HISTORY OF COPPER WELDING

Numerous publications in the past on the subject of welding the commercial grades of copper and copper alloys referred to various types of welding processes and a wide range of filler metal composition. A review of the literature on copper welding reveals that the reports and investigations dealt largely with the welding of copper alloys, and that references to the welding of commercial grades of copper are meager because of the difficulties involved in the welding of copper. Many of the references indicated the use of filler metals which were alloys of copper, such as the tin and silicon bronzes, which offered at that time the best solution to the problem. However, the use of these copper

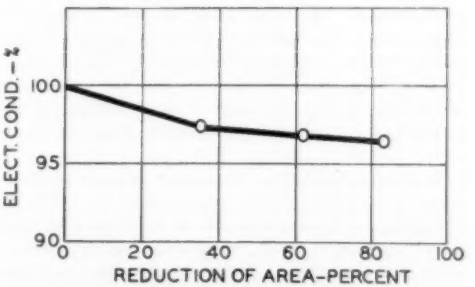


Fig. 6 Effect of cold reduction on conductivity of annealed tough pitch copper

alloys as filler metals results in a pronounced effect on the mechanical and physical properties of the weld metal in that the tensile strength is usually much higher than the parent metal and the electrical conductivity is reduced to low values. For some applications the corrosion resistance of the dissimilar weld metal was found to be poor. Many of the references also generally recommended the use of deoxidized copper material for welding, because of the difficulties that were generally encountered in obtaining sound welds in tough pitch copper material.[15–21, 29]

WELDING OF COPPER BY VARIOUS PROCESSES

The commercial grades of copper can be welded by several of the available welding processes. Until within the past few years, the commercial grades of copper, chiefly deoxidized copper, were welded either by the oxy-acetylene process or the carbon-arc process.

OXY-ACETYLENE PROCESS OF COPPER WELDING

One of the most commonly used welding processes is the oxy-acetylene process, which has been commercially applied for the welding of deoxidized copper. In general, the welding of copper by this process was limited to the deoxidized coppers. Tough pitch copper was found unsatisfactory for oxy-acetylene welding because of the reaction of the gases with the copper oxide, which made the welds brittle at the junction line and because of the porosity in the weld metal. With special precautions, tough pitch can be welded by the oxy-acetylene process, using a neutral flame. The filler metal which is most generally used for the welding of copper by this process is usually either a tin or silicon bronze or a silver-bearing copper filler wire, having approximately 1% silver.[2] One of the difficulties in oxy-acetylene welding of copper is the need for a great amount of heat which makes it necessary, in heavier sections, to require two operators to make butt seams successfully.[10, 21, 22, 29]

CARBON-ARC WELDING PROCESS

The carbon-arc process has also been used extensively in the welding of copper, using a procedure which requires maintaining a high arc and welding with high welding currents. The filler metal which is used in this process is either a tin or silicon bronze, and in some cases an aluminum bronze filler metal may be used. The carbon arc process, too, has been generally limited to the welding of deoxidized copper and is not recommended for the welding of tough pitch copper.[10, 18, 23–25, 29]

OTHER PROCESSES

The shielded metal-arc welding process using coated copper electrodes has also been used to some extent in the welding of commercial grades of copper. The filler metal or core wire which is used in the coated electrode was generally limited to either the tin or silicon bronze alloys. It is difficult to make high quality welds with coated copper electrodes because of the slag interference and porosity in the weld metal.[26]

The resistance welding process has also been used in the welding of commercial grades of copper and has been limited to the welding of very thin sections.[27, 29]

Flash welding has been limited to small and thin sections.[28]

Another process which has found limited application is pressure welding. Pressure welds have been made in commercial grades of copper with success. However, the process is limited to special design or shape, because of the problems involved in applying pressure. For pressure welding it is important that the parts to be joined are chemically clean.[29]

INERT-GAS METAL-ARC PROCESS

The development of the inert-gas metal-arc welding process has been applied to the welding of the commercial grades of copper with success. While this process can be classified under the consumable and nonconsumable metal-arc process, it is the latter process which will be discussed. The nonconsumable inert-gas metal-arc process is sometimes called "Heliarc" welding, while the consumable metal-arc process is commonly called by the trade name of "Aircomatic" or "sigma" welding. The welding of deoxidized copper by the consumable metal-arc process has been reported in literature. Satisfactory welds with good mechanical properties have been reported.[30–33] However, our experience with this process has indicated that special procedures are required and that some development is still necessary for the successful application of this process to the three grades of commercial copper. The welding of the three grades of copper by the nonconsumable inert-gas process, i.e., using tungsten as the metal electrode, will be given consideration in this presentation.

One chief advantage in the use of the inert-gas shielded-arc process is that the inert gas does not react with copper oxide, nor does it react with gases in weld metal or with any of the oxides present, to cause porosity or other defects in the weld. The purpose of the inert gas is to protect the molten copper from the oxygen of the air and to prevent gas evolution during the solidification of the weld metal.

This process has been in commercial use since 1940 and since that time it has rapidly developed into an important welding process, not only in the welding of copper, but in the welding of other metals such as magnesium, aluminum, titanium, molybdenum, and tungsten, stainless steel and many other new metal alloys.

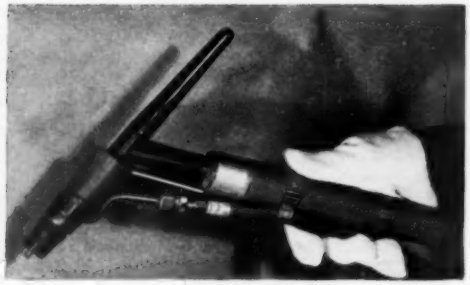


Fig. 7 Heliarc welding torch used in the nonconsumable metal-arc process

EQUIPMENT

The equipment which is used in the inert-gas metal-arc welding process consists of a welding torch or electrode holder, inert gas, either helium or argon, and a source of electric power, either direct current or alternating current. A typical welding torch which is used in the nonconsumable metal arc process is shown in Fig. 7 and a cross section is shown in Fig. 8. Primarily it consists of a water-cooled cable through which the welding current flows, connected to a holder which houses a collet for gripping the tungsten electrode. The important feature of the torch is the cup surrounding the end of the tungsten electrode. The cup must be either air or water cooled, depending on the amperage being used. The torches or holders are available in a variety of different capacities, depending on the amperage required. Torches for heavy-duty application are designed for operation with welding currents ranging up to 800 amp.

TYPES OF TUNGSTEN ELECTRODES

Two types of tungsten electrodes are now available, one a commercial grade of pure tungsten which was first introduced in this process, and the other type, thoriated tungsten, in which thorium oxide is incorporated into the tungsten.[34] The thoriated tungsten electrodes have special advantages useful in the welding of stainless steels and other metals. Experiments in the welding of copper with both thoriated and nonthoriated tungsten electrodes have indicated that the plain nonthoriated tungsten electrodes perform better than the thoriated grade. The thoriated tungsten electrode concentrates the arc stream, creating a cutting arc which results in deep undercutting of the parent metal. The cutting arc makes it more difficult to fuse the plate edges, and is of no apparent advantage in welding of copper. All the welds which were made and which are described in this presentation were made with the nonthoriated tungsten electrodes.

INERT GASES—HELIUM AND ARGON

Tests were made in deoxidized copper with helium and argon gases. The results obtained with helium were far superior to those obtained with argon gas, since with helium preheating was found unnecessary. Welding could be initiated almost immediately after striking the arc, without having to wait for the plates to be preheated before obtaining fusion of the parent metal. On the other hand, in using argon it was found necessary to preheat the copper plate to temperatures of 600 to 800° F before obtaining satisfactory fusion. It is possible to weld copper with argon gas without the necessity of preheating, but it will require holding the arc at the starting location for a certain length of time before fusion takes place. The arc voltage in helium is higher than that in argon under the same welding conditions, and this is shown in Fig. 9. It is believed that the higher arc voltage in helium liberates greater heat in the arc zone because of the dissipation of greater electrical energy and because of greater concentration of the arc stream.[35]

The thermal characteristics of the gases are also believed to be an important factor in the greater speed which can be obtained when welding with helium. Referring to the thermal properties shown in Fig. 10, the thermal conductivity and the specific heat of helium are approximately ten times greater than that for argon. The greater heat conductivity and higher specific heat of helium is believed to be largely responsible for the greater heat transmission in the arc zone, and permits

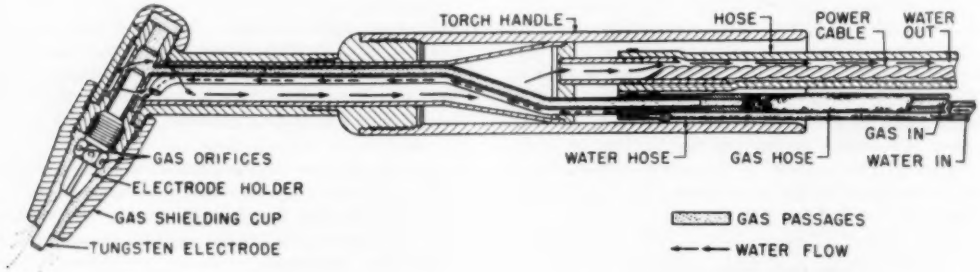


Fig. 8 Sectional view of HW-4 welding torch

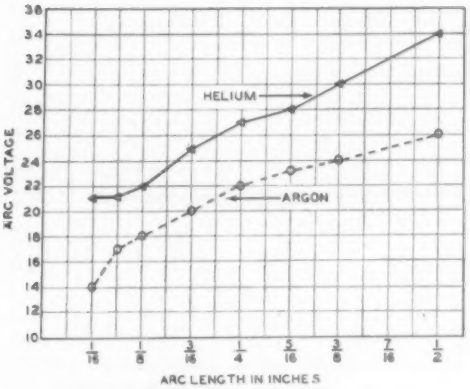


Fig. 9 The effect of arc length on arc voltage in helium and argon atmospheres

almost instantaneous fusion with the copper parent stock.

TYPE OF WELDING CURRENT

Experiments were made with both alternating and direct current in the welding of copper, and our tests have indicated that the best results were obtained when using direct current with the tungsten electrode on negative polarity. If positive polarity is used with the tungsten electrode, the tungsten will melt and transfer across the arc into the weld metal. The arc action with the positive polarity is also erratic and does not give good smooth performance.

Tests were also made with alternating current, using both the low and high open circuit voltage, with and without superimposed high frequency.

The welding performance with alternating current was unsatisfactory for the welding of copper because of the difficulty in maintaining the arc.

WELDING PROCEDURE

By welding procedure is meant the conditions under which the welding is performed, such as the type of welding groove used, the filler metal used, the current and amperage, arc length, welding speed, and welding sequence. Welding technique, by distinction, is that phase of welding which is controlled entirely by the skill of the welder, and involves the manipulation of the holder or filler rod, and the manner in which it is weaved, the consistency of maintaining uniform arc length, and the consistency of maintaining the proper angle of the holder and filler metal.

Groove Design

The groove design for butt welds depends largely on the thickness of the copper plate being welded. For plate thicknesses less than $^1/_8$ in. no bevel or preparation of the abutting edges is necessary. Above $^1/_8$ in. it has been found advantageous to bevel the edge of the plate to an included angle of 90 deg as shown in Fig. 11. The 90 deg included angle is used for plate thicknesses up to and including $^1/_2$ in. For these thicknesses of plates we have found that a 90 deg included angle has given us the best results. For plate thicknesses in excess of $^1/_2$ in. and including up to $1^1/_4$ in. in thickness, we have found a modified "U" type of groove satisfactory.

Sequence of Layer Deposition

Tests were made to determine the effect of the thickness of layers on the quality of the welds. It was found that there was no advantage in depositing thin

GAS	SPECIFIC HEAT AT 0°C.	THERMAL CONDUCTIVITY *
ARGON	0.1233	.0000369
HELIUM	1.2482	.0003386
HYDROGEN	2.4450	.0003270

*THERMAL CONDUCTIVITY EXPRESSED AS: CAL./SQ.CM./CM./SEC./DEG.C.

Fig. 10 Comparison of thermal properties of argon, helium and hydrogen gases

PLATE THICKNESS	SCARF DESIGN	NO. OF LAYERS	SEQUENCE OF DEPOSITION	SIZE OF TUNGSTEN ELECTRODE	AMPS.	VOLTS.	HELIUM FLOW L./MIN.
1/32 TO 3/32		2	1, 2	1/8	180 TO 220	22 TO 24	10
1/8 TO 7/32	90°	2	1, 2	3/16	240 TO 280	22 TO 24	10
1/4 TO 3/8	90°	2	1, 2	3/16	380 TO 440	24 TO 26	12
1/2	90°	3	2, 3, 1, 4	3/16	480 TO 520	24 TO 26	12
5/8 TO 3/4	1/4 TO 1/8	5	6, 7, 4, 5, 2, 3, 1, 8	3/16	480 TO 520	24 TO 28	12
7/8 TO 1-1/4	1 TO 1 1/4	6 TO 8	6, 7, 4, 5, 2, 3, 1, 8	3/16	480 TO 520	24 TO 28	12

Fig. 11 Recommended joint designs for various thicknesses of copper plates for welding in the flat position

layers. In fact, cracking difficulties were encountered when the first layer was deposited as a relatively thin pass. It was necessary in all cases to deposit a heavy layer for the first pass of weld metal. The sequence of layer deposition for various thicknesses of copper plate is shown in the recommended chart, Fig. 11.

The diameter of the filler wire may vary from 1/16 to 1/8 in. for plate thicknesses up to 1/8 in.. In the welding of plate thicknesses from 1/8 to 7/32 in., 3/16-in. diameter filler wire is used, with one layer on each side of the plate. For thicknesses from 1/4 to 3/8 in., two layers are used, using 3/16-in. diameter filler wire. For 1/2-in. plate, four layers are used, with 3/16-in. filler wire for the first layer, 1/4-in., diameter wire for the second and third and 3/16-in. diameter wire for the welding of the bottom layer. For the welding of 5/8 to 1 1/4 in. thicknesses, 3/16-in. diameter filler wire is used for the first pass, followed by 1/4-in. filler wire for subsequent passes. The amperages recommended to weld various plate thicknesses are given in the chart and vary from 180 to 520 amp, depending on the size of the tungsten which is used, and on the thickness of the plate material. While 1/4-in. tungsten electrodes may be used in the amperage range of from 450 to 600, it has been our experience that greater arc stability is obtained with 3/16-in. diameter tungsten electrodes without excessive tungsten consumption. The arc length was so adjusted that the voltage across the arc varied from 22 to 26 v, depending on the thickness of the plates being welded. This is shown in the chart, where the lower voltages were used on the thinner plates. The amount of helium gas used varied from 10 to 12 liters per minute, as shown.

For welding in the flat position it was found necessary to use a copper backup under the butt joint. The copper bar had a recessed groove of 1/32 in. in depth by 1/4 in. in width directly below the abutting edges of the plate. A typical backup bar which was used in the welding of a large number of 1/2-in. copper test plates is shown in Fig. 12.

In welding the reverse or bottom side of the weld, the groove was prepared for welding by chipping out the fused weld metal which was deposited from the top side. The chipping was done to a depth of approximately 3/16 and 5/16 in. in width. The welding procedure for the reverse side is the same as that indicated.

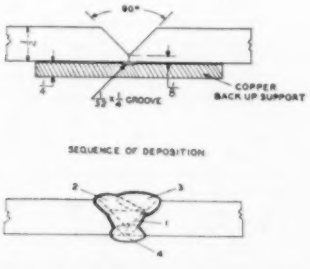


Fig. 12 Welding groove assembly for 1/2-in. thick deoxidized copper plate

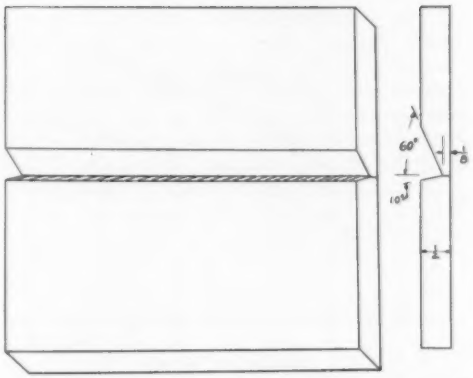


Fig. 13 Scarf design for welding in the horizontal position

In nearly all welds, 3/16-in. diameter filler metal was used.

Position Welding

The welding which was conducted in this investigation was made primarily in the flat position. Welding procedures for other positions were also investigated and it was found entirely practical to weld in the horizontal and vertical positions. It was necessary to modify the welding grooves somewhat for the horizontal and vertical positions. For the horizontal position a typical scarf design is shown in Fig. 13. The groove preparation for welding in the vertical position for the thin plates required a slight amount of scarfing from one side, having an included angle of 90 deg. For heavy plates a double "V" scarf with a nose of 1/8 in. thickness and angle of scarf being 90 deg on each side of the plate is recommended. A typical weld in 1/8 in. deoxidized copper plate, made in the vertical position, is shown in Fig. 14.

Welding was also attempted in the overhead position with very little success. It is believed, however, that with some practice it might be possible to make small repair welds in the overhead position.

Plate Material

The investigation in the welding of the three types of commercial coppers, namely tough pitch, deoxidized and OFHC, was chiefly in 1/2 in. plate thicknesses

Fig. 14 Example of a weld in 1/8-in. deoxidized copper plate made by the Heliarc process in the vertical position

Table 3—Chemical Compositions of Copper Filler Metals

Type of copper	*Cu*	*Mn*	*Si*	*P*	*Sn*	*Ag*
OFHC	99.94	Trace	Trace	Trace	Nil	Nil
Tough pitch	99.96	Trace	Trace	Trace	Nil	Nil
Phosphorous deoxidized	99.89	Trace	Trace	0.026	Nil	Nil
Silicon deoxidized	99.65	Trace	0.30	0.013	Nil	Nil
Silver bearing	98.97	0.09	Trace	Trace	Nil	0.87
Tin bearing	98.80	0.16	0.35	Trace	0.63	Nil

Some work was carried out in $^1/_4$ in. plate thickness of the deoxidized and OFHC copper, but the greatest amount of work carried out in this investigation to determine the welding procedure was made in $^1/_2$ in. thick plates in both deoxidized and tough pitch copper. Tough pitch copper plate material for the welding tests was obtained in the form of $^1/_2$ in. thick by 6 in. wide copper bus bars, which were analyzed and found to be of grade corresponding to electrolytic tough pitch copper. The $^1/_2$ in. deoxidized copper plates used in these tests were excess plate material received for the fabrication of a copper-lined vessel. The deoxidized plate was purchased to ASTM B152-49T Type DHP copper, with a tensile strength in the range of 30,000 to 38,000 psi.

The $^1/_4$-in. thick oxygen free high-conductivity plate material was obtained through the courtesy of the University of Illinois, which had excess plate material available from a program which was sponsored by the Copper and Brass Research Assn.

Composition of Filler Metal

In the welding of the three grades of commercial coppers, a variety of commercially available copper filler metals of high purity were used. No tests were made with any of the copper alloy filler metals such as the tin bronzes, phosphorous bronzes, or silicon bronzes.

In this investigation, six types of filler metal were used, as shown in Table 3.

The OFHC copper strip was cut off from the $^1/_2$-in. plate in strips $^1/_4$ in. wide.

The type of tough pitch copper wire was in the form of trolley wire which was checked for its analysis and conductivity and was found to be of a grade of electrolytic pitch copper, as shown by the analysis.

The deoxidized copper wire was a commercial grade of phosphorous deoxidized wire purchased as American Brass No. 939 filler wire.

The silicon bearing wire was purchased as a commercial brand, known as Revere 102 Grade.

The silver-bearing wire which was used is known as American Brass Grade 110.

The tin-bearing filler wire which was used extensively in this investigation was purchased from American Brass as their Grade No. 372.

Samples of these filler metals were tested for electrical conductivity and values are shown in Table 4.

Table 4—Electrical Conductivity of Various Copper Filler Metals (As Received)

Type of wire	*Conductivity, %*
OFHC	101.30
Tough pitch	100.47
Deoxidized (Phosphorus)	84.50
Silicon deoxidized	32.16
Silver bearing	86.80
Tin bearing	29.22

Welding Techniques

One of the most important factors in the successful welding of the commercial grades of copper is the welding technique. Of particular importance in welding technique is the direction of travel and filler metal addition, which is expressed as either forehand or backhand method of welding. These two methods of welding have a direct bearing on the extent of cracks which may be encountered in the welding of commercial grades of copper.

From our investigation, it has been found that on the lighter plates, less than $^1/_8$ in., the forehand technique is satisfactory. However, on plates heavier than $^1/_8$ in. we have found it very advantageous to use the backhand method of welding. The forehand and backhand directions of welding are shown in Fig. 15. It is evident that in the forehand welding the holder or torch is advanced from right to left and the filler wire is added as shown in the sketch. In the backhand travel, the holder or torch is moved from left to right, as shown in the sketch. The position of the torch and filler wire is relatively the same, as indicated. During the welding, the torch is manipulated from side to side to fuse the side walls of the parent stock in such a manner that as the side wall fuses, the

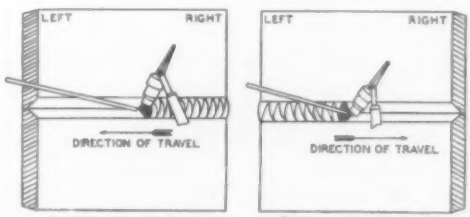


Fig. 15 Sketches which illustrate the forehand and backhand techniques of welding

filler metal is added at the right time to fill up the puddle and add the required amount of filler metal. Figure 16 shows a cross section of the weld in the forehand method of welding.

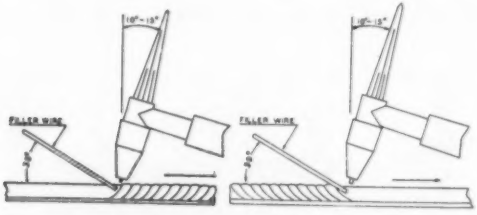
For the purpose of explaining the reason why we believe the backhand method is more effective in eliminating cracking difficulties, the angle of the torch is held at 10 to 15 deg from the vertical, with the filler wire at an angle of 30 deg from the horizontal. The torch is oscillated gently from side to side, as shown in the sketch. The angle of the torch is not deviated substantially from that shown, with the result that the arc force is concentrated directly under the puddle, and as the torch is moved from side to side, it is directed in advance of the puddle so as to preheat the parent stock. It is believed that in the advancing of the torch in the forehand method, the parent stock directly ahead of the puddle is heated and in that manner is expanded, causing a force or stress on the puddle or solidified weld metal.

In Fig. 17 a cross section of the backhand welding method is shown. The torch and filler wire are held in relatively the same position, with the exception that the torch is directed on the puddle of the weld being formed, and in that manner it causes a gradual solidification of the puddle without creating any critical stress during the solidification of the puddle. This action, in our opinion, is believed to be responsible for the very marked improvement in the successful procedure which was developed with this welding technique. It should be pointed out, however, that the backhand method of welding for copper is not new, but has been reported in literature for welding of copper by the oxy-acetylene process.[2, 18]

It is important that the operator be fully aware and observant of the characteristics of copper, and the fact that fusion takes place almost instantly, and that skill is necessary to be able to manipulate the torch and filler wire simultaneously.

Effect of Peening

Extensive investigation was carried out on the effect of peening on the quality of the weld metal. While



Forehand welding — Backhand welding

Fig. 16 Cross-sectional sketch to show the relative positions of Heliarc torch, filler wire and weld metal, in the forehand welding technique

Fig. 17 Cross-sectional sketch to show the relative position of Heliarc torch, filler wire and weld metal in the backhand welding technique

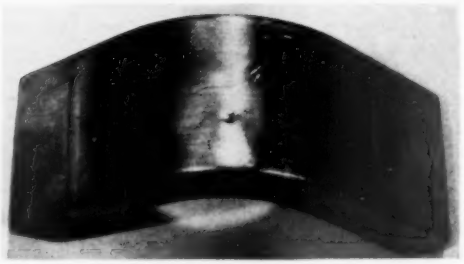


Fig. 18 Example of a fissure in longitudinal bend specimen

welds in heavy plate can be made without peening, the effect of peening, however, is to prevent the formation of fissures, and if properly performed will also result in fine grain structures. It has been our experience that in making single pass welds, fissuring is generally not encountered. When multiple pass welds are made, the problem of fissuring is present and can be eliminated completely by proper peening procedure. A typical example of a fissure in a bend-test specimen is shown in Fig. 18.

Fissures in general are microcracks which are located between the grain boundaries and are generally of limited extent, usually not exceeding $^1/_8$ in. in the greatest dimension. When specimens which have fissures are bent, the fissures are opened up as shown in Fig. 18. There has been no evidence to date to indicate that fissuring will initiate a crack and cause a crack to extend for any considerable distance. This is probably because the copper welds appear to be insensitive to crack propagation and the problem of fissuring is not important except where severe corrosion problems are encountered.

Peening was performed by using a pneumatic air hammer and a peening tool which is about $^1/_2$ in. in diameter with a radius of approximately $^1/_{16}$ in. on the periphery. The entire weld area is thoroughly peened, and in cases where the weld is flush with the surface of the plate, the peening is extended approximately $^1/_8$ to $^1/_4$ in. beyond the junction line of the weld. Where the bead reinforcement was considerably higher than the surface of the plate, the excessive bead reinforcement was removed by chipping prior to the peening operation. Typical appearance of peened and unpeened surface of a single-pass weld in $^1/_2$-in. deoxidized plate is shown in Fig. 19.

In Fig. 20 we have a complete test plate which has been peened over the entire weld area, according to the established procedure.

Tests which were made by peening indicated that fissures can be eliminated by peening of each layer after it is deposited. It has been our experience that a single-pass weld is generally free from fissures, but that as additional passes are deposited, the subsequent passes create sufficient stress on the previous passes to cause fissures to occur.

Fig. 19 Examples of peened and unpeened surface of a single-pass weld deposited in $^1/_2$-in. deoxidized copper plate

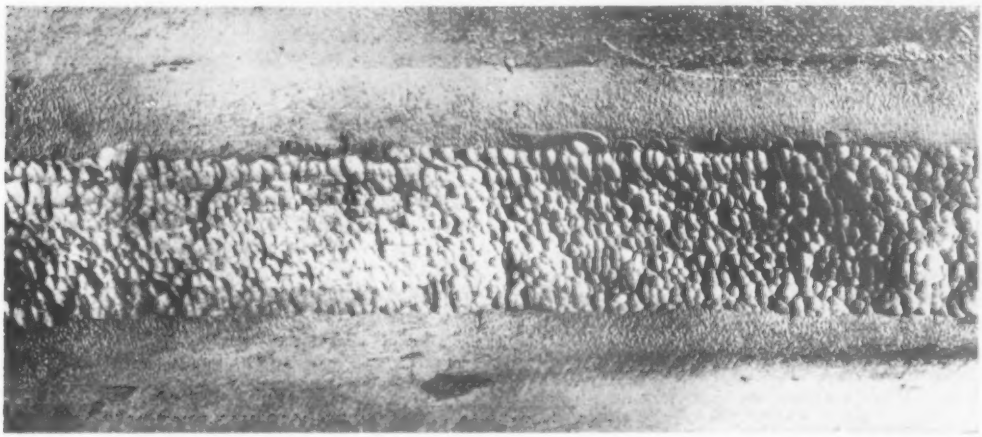


Fig. 20 Appearance of weld area after the peening operation; $^1/_2$-in. deoxidized copper plate and Grade 372 filler metal

Another result of peening is an increase in hardness which is caused by the deformation of the weld metal. A hardness survey of peened weld metal is shown in Fig. 21. These macrophotographs show a one-pass weld in $^1/_2$-in. deoxidized copper, in which the top surface of the weld metal was peened. The upper macro shows hardness values in the weld after peening. The maximum hardness of 128 VHN hardness was obtained near the upper surface, while the center of the weld had a hardness of approximately 76 to 80 VHN. The lower macro which was taken of the same weld after a stress anneal at 1000° F shows a reduction in the hardness of the peened weld metal, which also reveals a recrystallization of the top portion of the weld metal. The hardness values have been reduced to approximately 62 to 68 VHN.

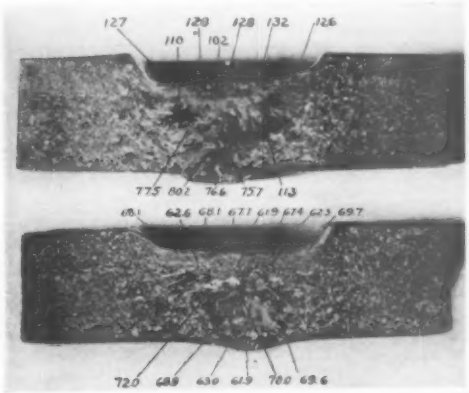


Fig. 21 Cross-sectional hardness survey of penned weld metal, also shown in Fig. 19

(Top) Peened, as-welded. *(Bottom)* Peened and stress annealed at 1000° F. Vickers hardness, 5 kg

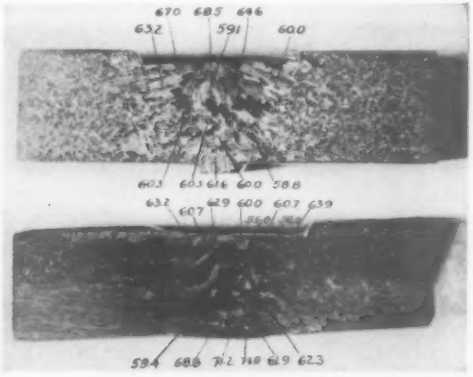


Fig. 22 Cross-sectional hardness survey of unpeened weld metal, also shown in Fig. 19

(Top) Not peened, as-welded. *(Bottom)* Not peened, stress annealed at 1000° F. Vickers hardness, 5 kg

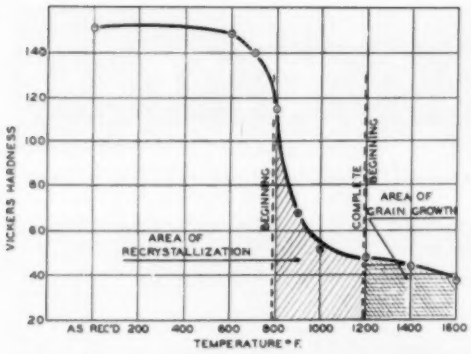


Fig. 23 Effect of temperature on recrystallization and hardness of peened tin-bearing copper weld

Figure 22 shows a macro of a one-pass tin-bearing weld in deoxidized copper which was not, peened and shows that in the as-deposited condition the weld metal is relatively soft, the values being 63 to 68 VHN. The lower view reveals the same section after the specimen was stress annealed at 1000° F for $^1/_2$ hr. The hardness of the unpeened specimens has not been changed after the stress annealing treatment.

Recrystallization

A study was made on the effect of temperature on recrystallization of peened tin-bearing type of weld metal. Figure 23 shows the relationship of hardness of the peened weld metal vs. annealing temperature. It is evident that as the temperature is increased from 200 to about 600° F no hardness change occurs. At temperatures above 600° F there is a marked drop in the hardness values of the weld metal, ranging from 153 to 49 VHN after 1200° F heat treatment. Accompanying this change in hardness, a microexamination of the weld areas indicated that the peened metal begins to recrystallize at a temperature of approximately 800° F. At 1200° F the recrystallization is complete. At temperatures above 1200° F there is evidence of grain growth in both the weld metal and parent stock.

In Fig. 24 is shown a typical one-pass tin bearing copper weld deposit in $^1/_2$-in. deoxidized copper plate. The top macro shows the as-welded condition of the peened and not peened weld metal. The left-hand side of the upper macro is unpeened, while the right-hand macro is peened, both being in the as-welded condition without any other subsequent heat treatment. The lower macros of these welds indicate that in the case of the unpeened weld metal, stress annealing at 1000° F for $^1/_2$ hr has produced no change in the macrostructure of the weld metal.

In the lower right-hand macro, the weld which was peened and given the stress anneal of $^1/_2$ hr at 1000° F, the top of the weld metal was recrystallized.

Figure 25 shows a tin-bearing copper weld in which only the top layers were peened and the macro in the upper photograph shows the effect of welding the bottom pass. This shows that recrystallization has occurred as a result of the welding heat from welding the bottom layer. The lower macro shows the same sample which was given a stress anneal at 1000° F, which did not affect the microstructure of the bottom part of the weld, since it was not peened. There is a slight further grain refinement in the upper portion of the top pass of the weld.

Figure 26 illustrates a tin-bearing weld in $^1/_2$-in. deoxidized copper plate made in three layers, in which all layers were peened. The upper macro is a cross section of the weld in the as-welded condition, and shows the effect of heat from welding the bottom pass on the top peened weld metal. In the lower macro the weld was given a stress anneal at 1000° F for $^1/_2$ hr and shows grain refinement in the bottom pass which was peened. It also shows that the remaining weld did not materially change in macrostructure.

Fig. 24 Cross sections through single-pass weld to illustrate the extent of recrystallization of the peened weld metal as a result of annealing treatment at 1000° F for $^1/_2$ hr.
(Top specimens) As-welded condition. (Lower specimens) Stress annealed at 1000° F for $^1/_2$ hr

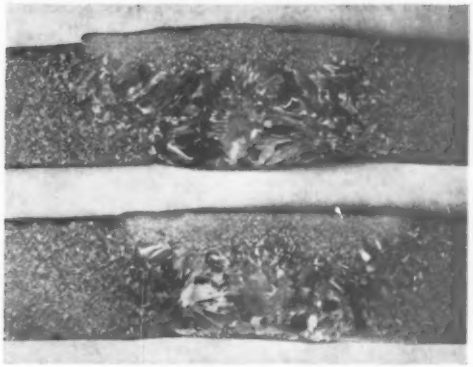


Fig. 25 Macrophotographs of tin-bearing copper weld which show the recrystallized portion of the top layer, which was peened

(*Top specimen*) As-welded condition. (*Lower specimen*) Stress annealed at 1000° F for $^1/_2$ hr

There is some indication of an additional grain refinement, but this is not very pronounced.

It is recommended that after welding and peening of the last pass, the welds be given an annealing treatment in order that the last layer may also be recrystallized.

From these macroexaminations, it is apparent that grain refinement of the coarse columnar weld metal structure can be accomplished by peening and by subsequent stress annealing. These results have also been verified by microexamination, which will be described later.

The effect of annealing on a tin-bearing weld and deoxidized copper plate at a temperature of 1600° F is shown in Fig. 27. This shows a marked grain growth in the weld metal and in the parent stock. Referring to the recrystallization chart, Fig. 23, stress annealing at a temperature above 1200° F results in grain growth.

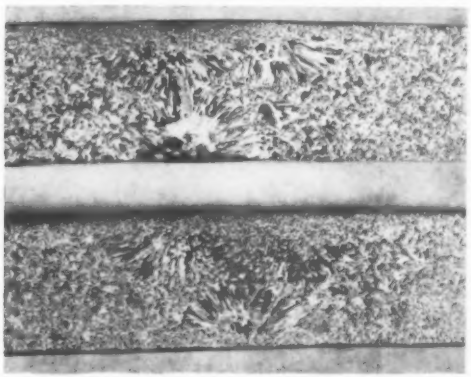


Fig. 26 Macrophotographs of tin-bearing copper weld metal deposited in three layers which show the recrystallized areas of the peened top and back side layers

(*Top specimen*) As-welded condition. *Lower specimen*) Stress annealed at 1000° F for $^1/_2$ hr

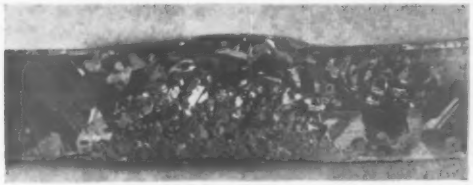


Fig. 27 Macrophotograph of tin-bearing copper weld after heating at 1600° F for $^1/_2$ hr

Note the increase of grain size in both weld metal and deoxidized copper plate

The macro of this figure shows the extremely coarse grain growth in the parent stock adjacent to the weld. There is some coarsening of the recrystallized top weld metal. There is also evidence of internal oxidation as shown by the thin layer in both parent stock and in the weld metal, as a result of the penetration of the copper oxide, due to heating at the high temperature. It is apparent that the depth of oxidation is considerably less in the weld metal than in the parent stock, as shown by the thickness of this band of internally oxidized copper.

Mechanical Properties

The mechanical properties of the welds which were made in the tough pitch, deoxidized and OFHC copper were determined on all-weld tensile specimens, joint tensile specimens, face and root bends across the welds, longitudinal bends and impact specimens of the weld and parent stock.

Mechanical properties were made in the as-welded and annealed conditions, and the tests indicated that there was no significant difference in the tensile strengths. The annealing treatment consisted of heating the welds or specimens to 1000° F for $^1/_2$ hr, followed by normal air cooling. No significant difference in the strength of the joint tensile tests between the as-welded and annealed specimens was observed. Similarly, in the bend specimens no significant effect was observed. From the large number of specimens tested, only typical values are tabulated.

The mechanical properties in the deoxidized and tough pitch copper plates were made in $^1/_2$-in. plate, using the various types of filler metal which were described earlier. A summary of the all-weld tensile properties which were made in the tough pitch and deoxidized copper plates is shown in Table 5. Referring to the tough pitch copper base plate, it is apparent that the tough pitch copper filler metal gave low values, whereas welds made with the tin-bearing filler metal and silver-bearing and silicon-deoxidized filler metal gave values which are equal or slightly higher than the strength of the copper plate. The elongations for these three types of weld metal are satisfactory and indicate that the metal possesses good ductility.

The phosphorous-deoxidized weld metal in tough

Table 5—Mechanical Properties of Copper Welds

Type of base plate	Type of filler metal	All-weld tensile specimens* Yield strength, psi	Tensile strength, psi	% Elongation in 1.4 in.	% Reduction of area	Condition
Tough pitch copper	Tough pitch copper	15,390	21,600	8.6	8.5	AW†
Tough pitch copper	Tin-bearing copper	18,610	29,600	28.6	50.4	AN‡
Tough pitch copper	Silver bearing	15,490	32,000	36.4	42.9	AN
Tough pitch copper	Silicon deoxidized	17,490	29,400	22.8	Broke at shoulder	AN
Tough pitch copper	Phosphorous deoxidized	12,000	26,500	23.6	35.5	AN
Deoxidized copper	Tough pitch copper	18,300	24,300	....	Broke at shoulder	AW
Deoxidized copper	Tin bearing	23,490	34,800	33.5	49.8	AW
Deoxidized copper	Silver bearing	20,610	32,500	41.4	48.2	AW
Deoxidized copper	Silicon deoxidized	17,900	30,700	42.8	42.0	AW
Deoxidized copper	Phosphorous deoxidized	17,500	27,000	19.3	27.5	AW

* Type of specimens: 0.357 in. diameter.
† AW—As-welded.
‡ AN—Annealed at 1000° F. for 1/2 hr and normal air cool.

pitch copper plate was somewhat lower than this value, with fair elongation and reduction of area.

In the welds made in the deoxidized copper plate, the tensile strength of the tin bearing, silver bearing and silicon deoxidized weld metal was equivalent or higher than the base plate, with excellent elongation and reduction of area.

The tough pitch and phosphorous-deoxidized copper welds were lower in strength than the parent plate.

Joint Tensile Tests

The results of the joint tensile specimens which were made in the tough pitch, deoxidized copper, and the OFHC copper plates are shown in Table 6. The results of the various types of filler metal in the tough pitch copper are shown in the upper portion of the chart, and indicate that the strengths of the tin-bearing, silver-bearing and phosphorous-deoxidized copper welds were equivalent to the strength of tough pitch copper plate. The tough pitch copper weld was low in tensile strength and failure occurred in the weld metal.

The joint tensile tests made in the deoxidized copper plate indicated that the tin-bearing, silver-bearing and silicon-deoxidized weld metals were entirely satisfactory, and that the fractures occurred in the parent metal. The tensile specimens of the tough pitch weld metal, the phosphorous-deoxidized weld metal, and the OFHC weld metal failed in the welds, with values approximately that of the deoxidized copper base metal.

In a series of tests made with the OFHC copper plate material, the weld metal with the OFHC filler metal was low in strength, with failure in the weld at a value of 16,350 psi. The tin-bearing copper filler metal, the silicon-deoxidized filler metal and the phosphorous-deoxidized filler metal failed at values that were either higher or equivalent to that of the parent plate.

Typical joint tensile specimens and two all-weld specimens are shown in Fig. 28. Excellent ductility of the weld specimens is clearly indicated.

Bend Tests Across the Weld

The results of the face-bend specimens made as free bends across the weld are shown in Table 7, and indicate that the welds made in tough pitch copper base plate were satisfactory for the tough pitch copper weld metal, the tin bearing, the silver bearing, and the phosphorous deoxidized, with elongation varying from 27 to

Table 6—Mechanical Properties of Copper Welds

Type of base plate	Type of filler metal	Joint tension specimens Yield strength, psi	Tensile strength, psi	Location of break	Condition
Tough pitch copper	Tough pitch copper	11,700	17,650	In weld	AN*
Tough pitch copper	Tin-bearing copper	13,000	32,210	In parent metal	AW
Tough pitch copper	Silver bearing	12,250	31,900	In parent metal	AN†
Tough pitch copper	Silicon deoxidized	11,610	23,400	At edge of weld	AN
Tough pitch copper	Phosphorous deoxidized	10,750	31,100	In weld	AN
Deoxidized copper	Tough pitch copper	11,450	29,500	In weld	AN
Deoxidized copper	Tin bearing	16,650	32,300	In parent metal	AW
Deoxidized copper	Silver bearing	12,170	30,300	In parent metal	AN
Deoxidized copper	Silicon deoxidized	13,110	31,000	In parent metal	AN
Deoxidized copper	Phosphorous deoxidized	11,600	29,000	In weld	AN
Deoxidized copper	OFHC copper	11,400	29,500	In weld	AN
OFHC copper	OFHC copper	9,440	16,350	In weld	AN
OFHC copper	Tin-bearing copper	12,410	31,400	In parent metal	AN
OFHC copper	Silicon deoxidized	12,090	32,200	In parent metal	AN
OFHC copper	Phosphorous deoxidized	10,910	30,600	In weld	AN

* AN—Annealed at 1000° F. for 1/2 hr. and normal air cool.
† AW—As-welded.

Table 7—Mechanical Properties of Copper Welds

Type of base plate	*Type of filler metal*	*Bend tests across weld*		*Condition*
		% Elongation in weld	*Remarks, face side in tension*	
Tough pitch copper	Tough pitch copper	27.5	180 deg, satisfactory	AN*
Tough pitch copper	Tin-bearing copper	34.5	180 deg, no defects	AN†
Tough pitch copper	Silver bearing	31.9	180 deg, no defects	AN
Tough pitch copper	Silicon deoxidized	26.3	100 deg, failed	AN
Tough pitch copper	Phosphorous deoxidized	32.5	180 deg, no defects	AN
Deoxidized copper	Tough pitch copper	24.7	180 deg, satisfactory	AN
Deoxidized copper	Tin bearing	52.0	180 deg, no defects	AW
Deoxidized copper	Silver bearing	31.0	180 deg, no defects	AN
Deoxidized copper	Silicon deoxidized	31.0	180 deg, no defects	AW
Deoxidized copper	Phosphorous deoxidized	40.0	180 deg, no defects	AN
Deoxidized copper	OFHC copper	3.8	12 deg, failed	AN
OFHC copper	OFHC copper	20.0	100 deg, failed	AN
OFHC copper	Tin-bearing copper	12.3	180 deg, no defects	AN
OFHC copper	Silicon deoxidized	18.0	180 deg, no defects	AN
OFHC copper	Phosphorous deoxidized	16.4	180 deg, no defects	AN

* AN—Annealed at 1000° F for ½ hr and normal air cool.
† AW—As-welded.

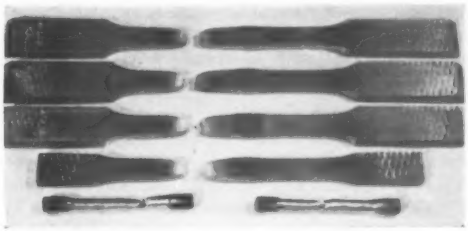


Fig. 28 Tensile specimens of tin-bearing copper weld which show the excellent ductility of both weld metal and deoxidized copper plate material

34%, with no failure to a 180 deg bend. The silicon-deoxidized filler metal failed at 100 deg, with elongation in the weld metal of approximately 26.3%.

Fig. 29 Face and root bends of deoxidized copper welded with tin-bearing copper filler metal

The face bends made in deoxidized copper made with the tough pitch filler metal, tin-bearing filler metal, silver-bearing filler metal and phosphorous-deoxidized filler metal all met the 180 deg bend, with elongation varying from 24 to 52%. The OFHC filler metal weld failed in the test with a bend of 12 deg and elongation of 3.8%.

Face bends made in OFHC base plate, with tin-bearing, silicon-deoxidized, and phosphorous-deoxidized filler metal met the 180 deg bend with limited elongation in the weld metal. The face bend with OFHC weld metal was unsatisfactory. Typical face and root bends are shown in Fig. 29. Typical longitudinal face bends are shown in Fig. 30.

Charpy Impact Tests

A series of Charpy impact tests was made using the standard Charpy keyhole notch type of specimen

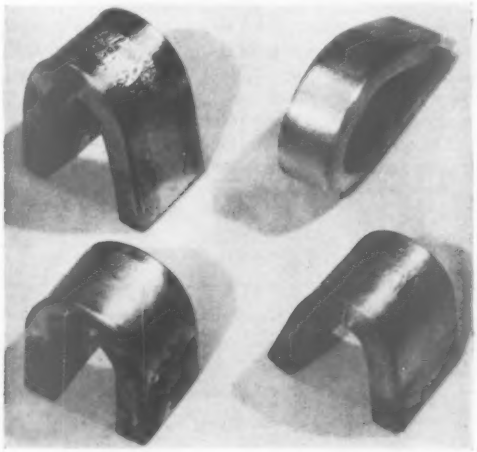


Fig. 30 Longitudinal bend specimens of tin-bearing copper weld in deoxidized copper plate material

Table 8—Mechanical Properties of Copper Welds

Type of base plate	*Type of filler metal*	*Impact resistance* Energy of rupture, ft-lbs At 75° F.*	*At −320° F*	*Condition*
Tough pitch copper	Tough pitch copper	4.0– 5.7	8.5–13.3	AW
Tough pitch copper	Tin-bearing copper	23.9–29.0	27.1–38.2	AW
Tough pitch copper	Plate metal only	26.7–30.2	34.1–37.9	AW
Deoxidized copper	Tough pitch copper	5.8– 8.2	9.8–12.0	AW
Deoxidized copper	tin-bearing copper	28.7–38.8	39.6–41.3	AW
Deoxidized copper	Silver bearing	15.6–21.9	19.2–23.9	AW
Deoxidized copper	Silicon deoxidized	36.6–38.8	38.8–43.6	AW
Deoxidized copper	Phosphorous deoxidized	10.4–11.7	7.8–13.3	AW
Deoxidized copper	Plate metal only	35.0–42.6	45.4–51.4	AW

* Type of specimens: Standard Charpy key-hole notch.
† AW: As-welded.

which was taken across the weld with the keyhole notch in the center of the weld. The weld metal tested was in the as-welded condition. The impact values, as shown in Table 8 indicate that for the tough pitch copper weld metal in tough pitch copper, the values are low at room temperature and are only slightly improved at −320° F.

The impact tests of the tin-bearing copper weld in tough pitch copper, range in value from 24 to 29 ft-lb at room temperature and 27 to 38 ft-lb at −320° F.

The tough pitch copper plate itself had a value of 26.7 to 30.2 ft-lb at room temperature and 34 to 37.9 ft-lb at −320° F.

The tin-bearing weld metal is equivalent in value to the plate material itself with respect to impact values.

For the tests which were made in the deoxidized copper, it may be seen that the values for the tough pitch copper welds in deoxidized copper are low and ranged from 6 to 8 ft-lb at room temperature.

The impact values for the tin-bearing weld metal in deoxidized copper base plate are high, and range from 29 to 41 ft-lb at room temperature, and at −320° F.

The impact tests for the silver-bearing weld metal in deoxidized copper plate indicated fair results with values ranging from 16 to 24 ft-lb at room and −320° F.

The silicon-deoxidized weld metal in deoxidized copper plate disclosed high resistance, with values ranging from 37 to 44 ft-lb at room and −320° F.

The impact results of the phosphorous-deoxidized copper weld metal in deoxidized copper plate were poor.

The deoxidized plate metal has good values, ranging from 35 to 42 ft-lb at room temperature, and from 45 to 51 ft-lb at −320° F.

In summarizing the results of the mechanical properties obtained on the copper welds made in various types of copper base plates, it is evident that welds made in tough pitch copper using tin-bearing, silver-bearing and silicon-deoxidized filler metal are satisfactory from the standpoint of tensile strength and joint efficiency. The bend specimens with these three filler metals are also satisfactory.

The tough pitch copper filler wire and phosphorous-deoxidized copper filler wire were unsatisfactory for welding in tough pitch copper, in that the tensile properties were deficient and in the case of the tough pitch copper weld metal, the impact values were low.

In summarizing the welds made in the deoxidized copper base plate, it is apparent that the tin-bearing, silver-bearing, silicon-deoxidized and phosphorous-deoxidized weld metal was satisfactory from the standpoint of tensile strength, both in the weld specimens and in the joint tension specimens. Bend tests made with these filler metals were also satisfactory. However, the impact resistance of the phosphorous deoxidized filler metal and the tough pitch copper filler metal was low, and cannot be considered entirely satisfactory.

In summarizing the mechanical properties of welds made in OFHC copper plate, it is apparent that the welds made with the tin bearing, silicon-deoxidized and phosphorous-deoxidized filler metals resulted in tensile strengths which were equivalent to that of the parent plate. The bend specimens which were of the same weld metal were satisfactory. Welds made with OFHC copper filler metal in OFHC stock were low and in general were unsatisfactory. This comment also applies to OFHC filler metal in tough pitch and deoxidized copper plates.

Table 9—Chemical Compositions of Copper Plates and Welds

Type of material—	*Cu*	*Mn*	*Si*	*P*	*Sn*	*Ag*
OFHC plates	99.94	Trace	Trace	Trace	Nil	Nil
Touch pitch plate	99.98	Trace	Trace	Trace	Nil	Nil
Phosphorous deoxidized plate	99.90	Trace	Trace	0.023	Nil	Nil
Tough pitch weld	99.95	Trace	Trace	Trace	Nil	Nil
Phosphorous deoxidized weld	99.96	Trace	Trace	0.020	Nil	Nil
Silicon-deoxidized weld	99.70	Trace	0.16	0.014	Nil	Nil
Silver-bearing weld	98.99	0.04	Trace	Trace	Nil	0.73
Tin-bearing weld	99.10	0.13	0.10	Trace	0.47	Nil

Chemical Analyses of Plate and Weld Metal

Chemical analyses were determined for the plate material and for the various types of welds. These are shown in Table 9. The OFHC and tough pitch plate are free from residual elements. No determination was made for the oxygen content which was present in the tough pitch plate However, the oxygen was identified as cuprous dioxide in the microstructure of the material.

For the phosphorous-deoxidized plate, 0.023% phosphorus is normal and is in the range for this type of material. The chemical analysis of the weld metal, as shown in the table, is normal for the type and composition of filler metal used.

The phosphorus in the phosphorous-deoxidized weld is normal and is recovered without appreciable loss from the filler wire.

The silicon deoxidized weld indicates that not only is there a residual of 0.30% silicon, but that there is a small amount of phosphorus present as shown.

The silver-bearing weld metal has a silver content of approximately 0.73% which indicates good recovery from the silver content from the filler metal.

The tin-bearing weld indicates that there is a residual of 0.47% tin, 0.13% manganese and 0.10% silicon. These values are normal and indicate that there was no substantial loss in these elements from those found in the filler metal.

Electrical Conductivity of Weld Metal and Base Metal

Electrical conductivity tests were made of the various types of weld metal compositions. These are shown in Table 10. The values were determined and were reported as per cent conductivity in terms of the International Annealed Copper Standard.

The conductivity tests indicated that the tin-bearing weld metal has a conductivity of 37%, while the silver-bearing weld metal had a conductivity of approximately 87%. The phosphorous-deoxidized weld metal is 83%, the silicon-deoxidized weld metal approximately 26%, the tough pitch copper weld metal 90% and the OFHC weld 95.4%. In general, the values of the electrical conductivity followed closely the conductivity of the filler metal used.

Table 10—Electrical Conductivity of Copper Welds

Type of Weld	*Conductivity, %**
OFHC copper	95.40
Tough pitch copper	90.60
Silicon deoxidized	26.56
Phosphorous deoxidized	83.00
Silver bearing	87.00
Tin bearing	37.04

* In terms of IACS = 100%.

In order to obtain weld metal of high electrical conductivity, the use of either the silver-bearing or the phosphorous-deoxidized filler metal is recommended. Of the two, only the silver-bearing weld metal gave the most satisfactory results, with respect to mechanical properties.

Inspection

Radiographic inspection of the welds was found to be the most suitable method of inspection for the detection of defects such as cracks, porosity and tungsten inclusions. A typical crack which was found by radiographic inspection and was not visible upon the surface is shown in Fig. 31. The weld was made with OFHC filler metal in deoxidized copper plate material.

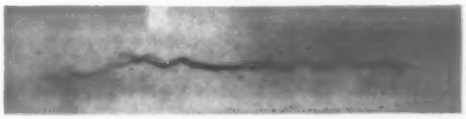


Fig. 31 A radiograph of OFHC weld metal in deoxidized copper plate material revealing a large crack

The presence of tungsten inclusions may indicate that either the tungsten electrode was not completely protected from oxidation, or the tungsten electrode touched the molten metal, and as a result small particles of tungsten were transferred to the weld. This can largely be eliminated by holding the proper arc length and angle of torch to keep the electrode free from contamination.

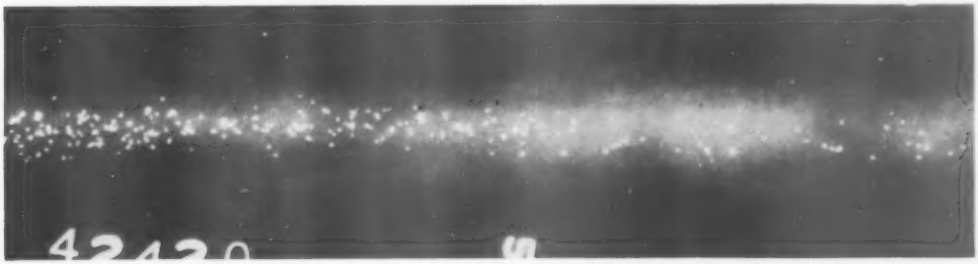


Fig. 32 A radiograph of tin-bearing copper weld in deoxidized copper plate material which illustrates the extent of tungsten inclusions found as a result of oxygen contamination

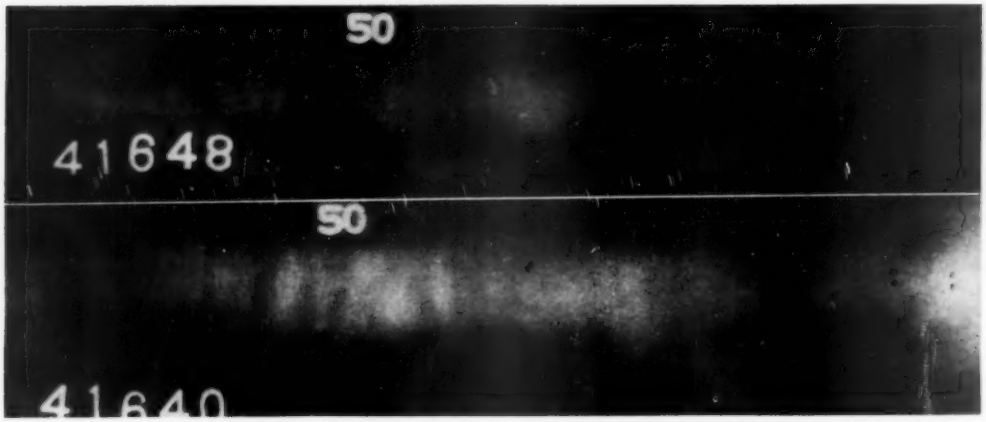


Fig. 33 Radiographs of tin-bearing copper weld in deoxidized copper plate material which are rated as satisfactory

Moisture in the gas or infiltration of oxygen may also cause rapid oxidation of the tungsten and may result in tungsten inclusions being found in the weld metal. A radiograph showing tungsten inclusions is shown in Fig. 32, which shows scattered tungsten inclusions, identified as white spots in the radiograph.

It is possible to produce copper welds which are completely free from tungsten inclusions by the observance of good welding procedure and carefully training an operator so that he is skillful in maintaining the proper arc length.

In Fig. 33 we have two radiographs of tin-bearing weld metal in deoxidized copper, which are considered satisfactory. The quality of these readiographs compares very favorably with the quality generally referred to for steel welds.

The examination of many radiographs of the various types of copper welds indicated that the tin-bearing and silicon-deoxidized types were free from porosity. The radiographs of welds made with silver-bearing and phosphorous-deoxidized filler metals contained a slight amount of scattered porosity. This was true irrespective of the base metals used.

Some of the defects that are encountered in copper welds, such as cracks, can be largely eliminated by using a proper welding procedure and the proper selection of filler metal. Porosity can also be overcome by the proper selection of filler wire and welding sequence. One of the defects commonly encountered in copper welds is the presence of microfissures. These microfissures are very difficult to detect unless the copper weld is carefully ground, polished and etched with

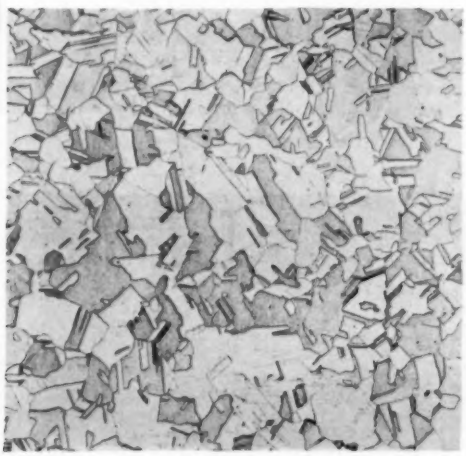


Fig. 34 Microstructure of OFHC copper plate material. × 100

Fig. 35 Microstructure of tough pitch copper plate material. × 100

a suitable etching agent. A low-powered magnifying glass is helpful in finding the presence of microfissures. Microfissures can be largely eliminated by means of a thorough peening procedure.

Microstructure of Weld Metal and Parent Stock

Metallurgical examinations were made of the various deposited welds and photomicrographs of these were prepared by the A. O. Smith Metallurgical Research Department. The microstructure of a given type of weld metal and of the junction area is the same, regardless of the type of base plate material used. In other words, the microstructure for the tin-bearing filler metal, whether it is made in deoxidized copper, tough pitch copper, or oxygen-free copper, has a similar microstructural appearance. The same comment applies to the other types of filler metals which were used.

A typical microstructure of OFHC copper stock is shown in Fig. 34. The micro examination of the OFHC copper indicates a structure which is devoid of copper oxides, is clean and shows twins which are the result of annealing following straining.

A microstructure of tough pitch copper is shown in Fig. 35. The microstructure of the tough pitch copper plate shows a network and stringers of cuprous oxide which is typical of this type of material. The grain structure in the background was etched lightly in order to show the cuprous oxide pattern. A light etch was used in the preparation of this microstructure.

Figure 36 shows the microstructure of deoxidized copper plate stock. The deoxidized copper structure is similar to oxygen-free high-conductivity copper in that the stucture is free from cuprous oxides and also shows twins, which is typical of strained material which has been annealed.

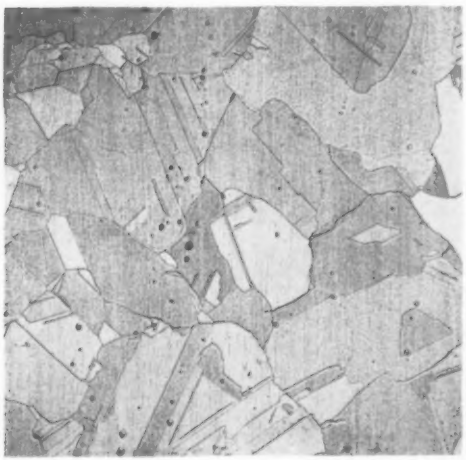


Fig. 36 Microstructure of deoxidized copper plate material. × 100

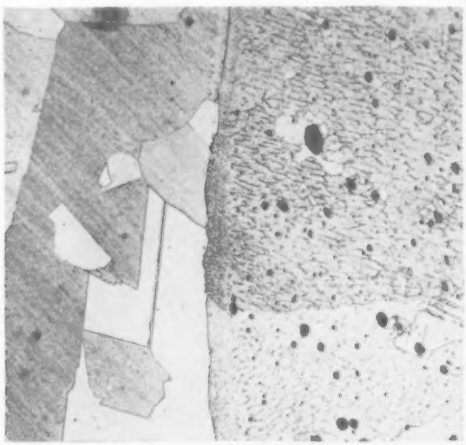
Copper plate Weld metal

Fig. 37 Microstructure at interface between OFHC copper weld and deoxidized copper plate. × 100

The micro-structure of the OFHC filler metal in deoxidized-copper plate is shown in Fig. 37, which shows the junction line between stock and weld.

Figure 38 shows the microstructure of tough pitch copper filler metal in deoxidized copper stock. The microstructure shows the network or pattern of cuprous oxide in the weld metal, which is on the right-hand side. In addition, the micro also shows typical microporosity in the weld.

Figure 39 shows the structure of phosphorous-deoxidized filler metal in deoxidized copper stock, and shows the typical structure at the junction of the weld metal, which is on the right-hand side, and parent stock. It is devoid of cuprous oxide network. This



Copper plate Weld metal

Fig. 38 Microstructure at interface between tough pitch copper weld and deoxidized copper plate. × 100

weld metal, however, does contain microporosity which is shown as round dots in the microstructure, which is also shown in Fig. 40.

Figure 41 shows the microstructure of the junction or interface of silicon-deoxidized filler metal in deoxidized plate stock. The microstructure is free from cuprous oxide and is relatively free from porosity and other defects.

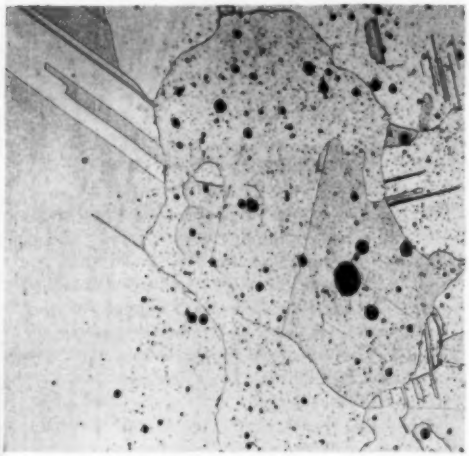
Figure 42 shows the microstructure of silicon-deoxidized weld metal only.

Figure 43 shows the microstructure of the junction or interface of silver-bearing filler weld metal in deoxidized stock. This microstructure is free from cuprous oxide. However, microscopic examination of this weld disclosed that it contains a small amount of microporosity.

Figure 44 shows the microstructure of the interface of tin-bearing filler weld metal in deoxidized stock, and reveals a structure which is free from cuprous oxide and from microporosity.

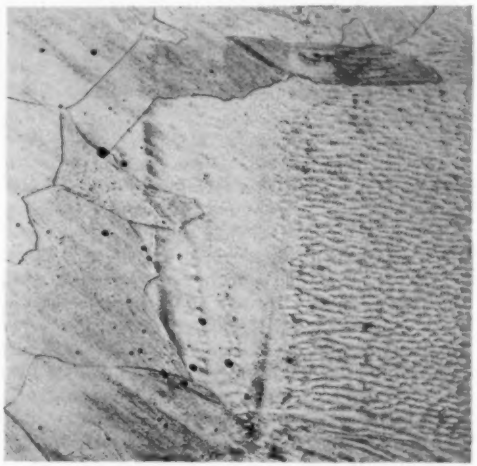
Figure 45 shows the microstructure of tin-bearing weld metal which has been given a stress anneal at 1000° F for $\frac{1}{2}$ hr. The weld metal shows a medium size grain after the peened weld metal was annealed.

Figure 46 shows the structure of tin-bearing weld



Copper plate Weld metal

Fig. 39 Microstructure at interface between phosphorous-deoxidized copper weld metal and deoxidized copper plate. × 100



Copper plate Weld metal

Fig. 41 Microstructure at interface between silicon-deoxidized copper weld metal and deoxidized copper plate. × 100

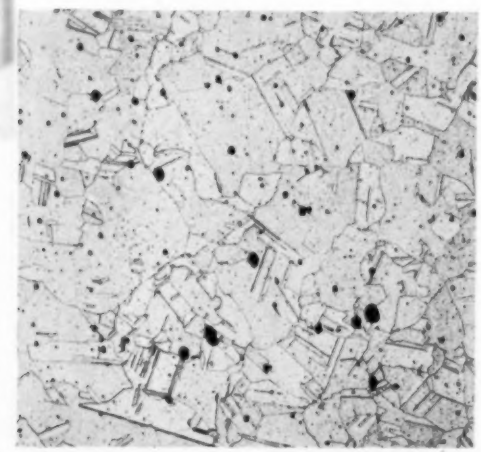


Fig. 40 Microstructure of weld deposit made with phosphorous-deoxidized copper filler metal in deoxidized copper plate. × 100

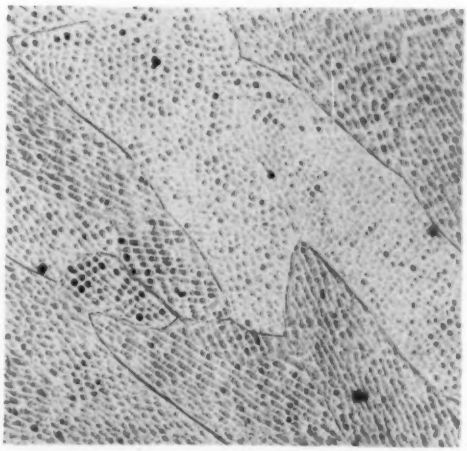


Fig. 42 Microstructure of weld deposit made with silicon-deoxidized copper filler metal in deoxidized copper plate. × 100

metal after 1600° F anneal, and shows the enlarged grains which are the result of grain growth at this temperature.

Figure 47 shows deoxidized copper plate material after 1600° F anneal, and also shows the enlarged grain growth which occurred in the parent metal as a result of high-temperature anneal.

In summarizing the microstructure of the various types of weld metal, it is evident that only the tough pitch copper weld metal disclosed the presence of cuprous oxide.

In the phosphorous deoxidized and silver bearing weld metals, the microstructure does not contain cuprous oxide but the weld metal does contain a small amount of fine scattered porosity. In both silicon-deoxidized and tin-bearing welds, there is complete absence of porosity and cuprous oxide.

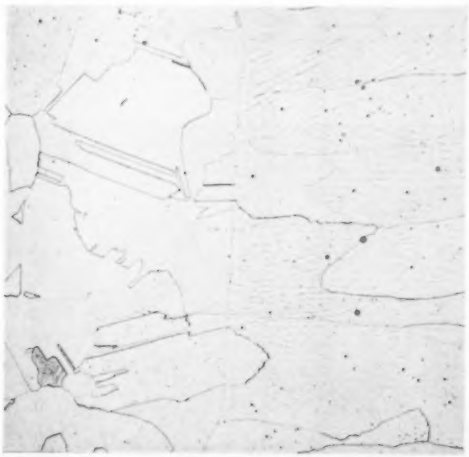
The tin-bearing and the silicon-deoxidized welds were free from microporosity. The silver-bearing and the phosphorous-deoxidized copper welds exhibited a small amount of fine scattered micro porosity. In all welds examined, the weld interface and parent metal were clean, and in some instances grain growth occurred across the junction line.

Typical Pressure-Vessel Fabrication

The welding procedure which was described in the making of the test plates was also used in the fabrication of four vessels, two of which were used as reactors and

Copper plate Weld metal

Fig. 43 Microstructure at interface between silver-bearing copper weld metal and deoxidized copper plate. × 100



Copper plate Weld metal

Fig. 44 Microstructure at interface between tin-bearing copper weld metal and deoxidized copper plate. × 100

Fig. 45 Microstructure of recrystallized weld metal made with tin-bearing copper filler wire in deoxidized copper plate. × 100

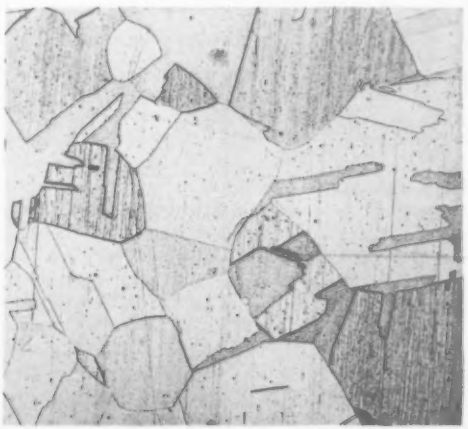


Fig. 46 Microstructure of tin-bearing copper weld metal after annealing heat treatment at 1600° F. × 100

Fig. 47 Microstructure of deoxidized copper plate material after annealing heat treatment at 1600° F. × 100

the cones and shell section is shown in Figs. 49 and 50. The completed cylindrical section, after the layers have been wrapped around the copper lining, is shown in Fig. 51. The typical connections to the vessel are shown in Fig. 52. The last figure, Fig. 53, shows the completed vessel prior to shipment.

In the fabrication of this vessel, numerous test plates were made to qualify welding procedure and operators. The welders who performed the copper welds were required to pass operator's qualification tests on copper plate by making standard ASME Operator's Qualification Tests. In addition these welds were examined radiographically, to verify their proficiency for copper welding.

In summarizing this investigation, a method was described for the welding of the three grades of commercial coppers which are produced today, using a variety of different types of filler metals. From the results which were described, high-quality copper weld metals can be produced which have mechanical and physical proper-

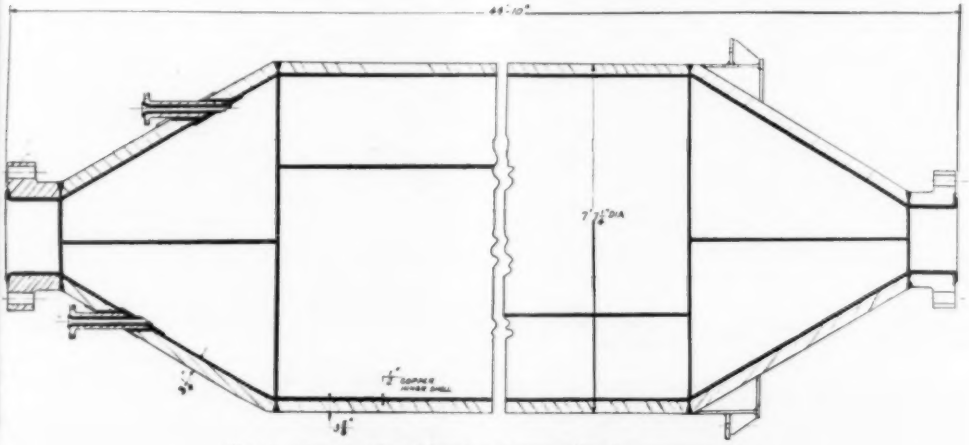


Fig. 48 Cross-sectional drawing of copper-lined pressure vessel

two as heat exchangers. A cross section of a reactor which was lined with $^1/_2$-in. deoxidized copper plate is shown in Fig. 48. A number of nozzles were welded in the top cone, which were also lined with copper. The inlets and outlets in the cone sections, as well as the flange faces, were also lined with the same type of copper. The outer cylindrical portion of the vessel was of layer-type construction. The operating conditions for this vessel were specified for a design pressure of 1050 psi gage, at a temperature of 570° F. The hydrostatic test pressure used was 2100 psi. All of the copper welds were inspected by radiographic means. The copper shell in the cylindrical section was welded and was stress annealed at 1000° F for $^1/_2$ hr after welding, and the cones after welding were also stress annealed prior to insertion into the cone sections. The carbon steel nozzles were stress relieved separately. Fabrication of

Fig. 49 Assembly of deoxidized copper plate segments for cone section of pressure vessel

Fig. 50 Cone assembly of deoxidized copper material (shown in Fig. 49 after welding the various seams and ready to be placed in the carbon steel outer shell)

Fig. 52 One of several nozzle assemblies which have been lined throughout the inside surface with deoxidised copper and seal welded around openings

ties similar to that of the parent material. It was shown that certain types of compositions of filler metal are markedly superior to other types. It has also been shown that the welding procedure is extremely important in obtaining satisfactory results.

These tests have also shown that the inert-gas metal-arc process is suitable for the production of high-quality weld metal. Undoubtedly, in the future further developments in the field of copper welding will take place.

In conclusion, may I emphasize that the findings as reported here would not have been possible without the assistance and cooperation of my staff in the Welding Research Laboratory, the assistance of the Metallurgical, Electrical, and Spectrographic Laboratories, and the management of A. O. Smith Corp., which has given me permission to publish this information.

Fig. 51 Shell assembly which has been lined with deoxidized copper

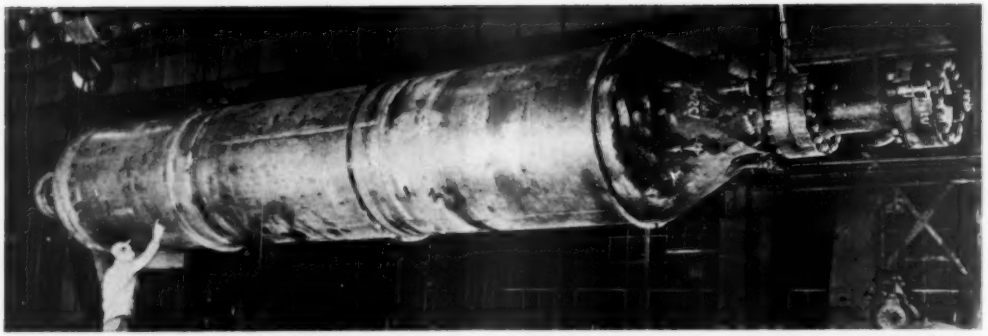


Fig. 53 Completed pressure vessel lined with deoxidized copper ready for shipment

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(*Continued on page 691*)

Production Welding 24ST3 Aluminum Using Slope Control

Some techniques and equipment developed for the successful production resistance welding of aluminum

by Robert E. Kemp

INTRODUCTION AND SUMMARY

AT THE American Seating Co., Grand Rapids, Mich., we have a single-phase welder qualified to resistance weld aluminum alloys, in accordance with MIL-W-6860 Government specification. We were requested to relate some of our experiences with this type of equipment for the benefit of those interested in welding aluminum.

As Mr. Johnson has pointed out, single-phase welding of aluminum with the use of positive and negative slope control has greatly reduced the trouble formerly encountered when welding aluminum alloys with single-phase equipment.

PROCEDURE AND EQUIPMENT

Cleaning Before Resistance Welding

After much investigation as to methods of cleaning which are employed by the various aircraft industries, it was decided to use one or more features of the various companies, since we felt this would achieve the best method for our company.

From the information we gathered, we decided to maintain our surface resistance at 35 micro-ohms or below. This is being accomplished consistently by the use of five tanks which are set up as follows:

Tank No. 1 is a spray type vapor degreaser. A spray type was required because of our 0.020 Al which would not clean properly in a conventional vapor degreaser.

Tank No. 2 is maintained at a temperature of 170° F ± 10°. The solution is Kelite No. 1, and the concentration is 4 oz. per gallon (maintained).

Tank No. 3 is a hot water rinse tank maintained at a temperature of 170° F ± 5°. This tank is arranged with suitable air agitation and constant water overflow.

Tank No. 4 is the etching tank and is the only tank which is stainless steel lined. The temperature is not regulated outside of normal shop conditions, which in this case would be room temperature. The concentration is 12 oz. per gallon of Oaklite No. 34 (maintained).

Tank No. 5 is a cold water rinse tank with temperature from 40 to 54°. This tank is equipped with suitable air agitation and constant overflow.

We have conducted experiments for 6 weeks, during which time the temperatures of all 4 tanks were varied and the records kept. No graph data are available at this time, although we feel free to say that trouble can be encountered if Tank No. 2 and Tank No. 4 temperatures are not controlled. This precleaning and etching process will give you consistent readings in micro-ohms from 2 to 10. At the present time we are holding aluminum for 24 hr. This time will be increased shortly to a possible 72 hr.

The illustrations shown were prepared to illustrate the equipment and show what can be expected when resistance-welding aluminum alloys with a single-phase welder. These illustrations will deal with positive and negative slope, pressure and microphotographs of several welds.

Equipment

The machine shown in Fig. 1 is rated at 100 kva, primary voltage 440/60/1 phase, 50,000 secondary amperes at 10 v. The pressure is furnished by a 6-in. diameter air cylinder connected to a low inertia head. Between the head and the piston are mounted four Belville springs, insuring fast follow-up. Solonoid valves control the air flow, and air pressure regulators control (*a*) slow approach, (*b*) weld pressure and (*c*) the forge pressure. The three switches on the right-hand side control the electrical circuit for the (*a*) slow approach, (*b*) tip dress and (*c*) "weld" and "no weld" current.

Robert E. Kemp is connected with the American Seating Co., Grand Rapids, Mich.

Paper was presented at a joint meeting of the AIEE-AWS-IEESD, at the Third Annual Welding Conference, Detroit, Mich., Apr. 17, 1952.

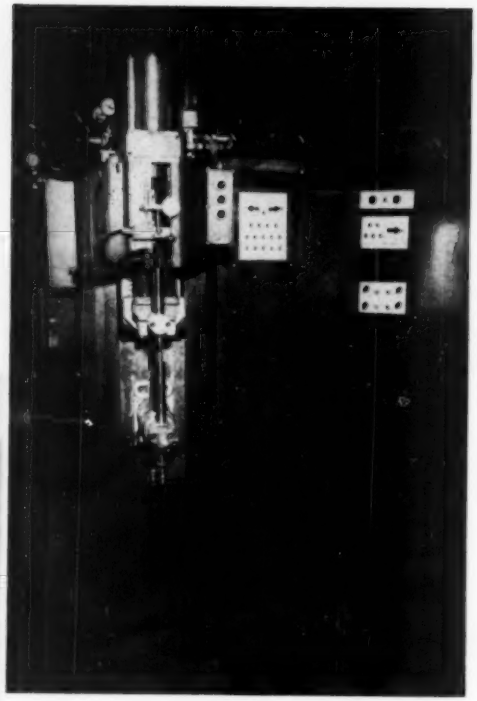

Figure 1

The barrel micrometer allows adjustment to close the microswitch at any predetermined pressure, as regulated by the air pressure control valves, and is shown on the dial indicator in thousandths. This also can determine the additional follow-up pressure, which will be referred to later as "overshoot."

The doors of the control have been left open to aid and clarify the explanation of the various controls and their functions. For ease in explanation we will explain the controls on the open door panel first, as they control to an extent the settings on the other dials. The dial on the right is the heat control dial; the switches to the left are the weld time switches. The four controls on the bottom are the: (*a*) "squeeze time," (*b*) "hold time," (*c*) the "forge time" and (*d*) the "off time." The panel on the front of the machine controls: (left-hand dial) the positive (+) slope control heat and (right-hand dial) the negative (−) slope control heat. The uppermost of the three rows of switches controls positive (+) heat time; the middle row controls negative (−) slope delay time; and the bottom row controls negative (−) slope time.

Figure 2 is a brush oscillogram showing typical weld time in cycles and a pressure graph for welding two thicknesses of 0.032 24ST3 Alclad. The top reproduction on this oscillogram illustrates one cycle positive slope, one cycle of weld heat and one cycle

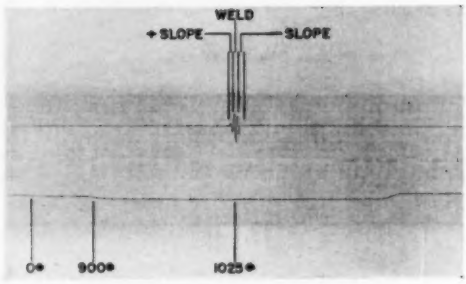

Fig. 2 0.032–0.032, 24ST3 Alclad aluminum

of negative slope. The lower graph shows the pressure as it advances during the welding cycle, from zero on the left-hand side, to slow approach up to 900 lb, then the final weld pressure of 1025 lb. This figure shows that we are on the conservative side in so far as welding pressure is concerned, as we are firing midway in our pressure cycle. How far back this welding cycle may be moved at the present ime, we don't know, nor do we know how far back we can move the "hold time" and still get a satisfactory weld. At this particular setting we are able to weld approximately 90 spots per minute.

Figure 3 shows the conditions which exist when welding two pieces of 0.064 24ST Alclad aluminum. It gives a rough idea on a larger scale of the terms "positive slope," "weld time" and "negative slope;" also "tailing time," which will enable the reader to understand the next figure which gives our various welding schedules. Figure 3 also shows the application on the pressure graph of the forging pressure being used. Note that the pressure starts on slow approach, goes directly up to 1000 lb, into overshoot to 1175 lb, at which time forge pressure comes in, raising the pressure to 2100 lb.

Regarding these two pieces of 0.064 Al it is also interesting to note that the forge pressure comes in at the beginning of the sixth cycle. At the start of our schedule run we experimented with bringing it in a great deal later, but our welds proved too hard, giving us a very hard shear value which caused much incon-

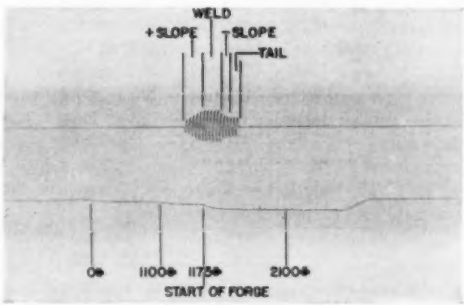

Fig. 3 0.064–0.064, 24ST3 Alclad aluminum

STOCK THICKNESS	ELECT. FORCE			CURRENT			TIME (CYCLES)				WELD NUGGET SIZE	ELECTRODE
	MICRO	OVER SHOOT	FORGE	+SLOPE	WELD	-SLOPE	+SLOPE	WELD	-SLOPE	TOTAL		
.020/.020	750#	825#	OFF	17,500	41,750	33,400	1	1	1	3	.214	4"
.020/.025	750#	825#	OFF	17,500	41,750	33,400	1	1	1	3	.188	4"
.025/.025	750#	825#	OFF	17,500	41,750	33,400	1	1	1	3	.210	4"
.025/.032	750#	825#	OFF	17,500	41,750	33,400	1	1	1	3	.190	4"
.032/.032	900#	1025#	OFF	16,100	46,000	36,800	1	1	2	4	.230	4"
.032/.040	900#	1025#	OFF	16,100	46,000	36,800	1	1	2	4	.250	4"
.020/.064	750#	880#	OFF	15,225	43,500	36,875	1	1	1	3	.185	4"
.064/.064	1100#	1175#	ON 2100#	24,250	48,500	29,100	3	7	TAIL 3 / 3	16	.308	4"

Figure 4

sistency. It was then that we started moving the forge pressure back to the beginning of the weld cycle, gradually obtaining a weld which was soft enough to take the Boeing bend test and give consistent shear values.

Figure 4 covers all the welding schedules which we are permitted to weld under specification MIL-W-6860, Class A. One interesting point is that the first four schedules, namely, 0.020 to 0.020, 0.020 to 0.025, 0.025 to 0.025 and 0.025 to 0.032, are all welded with the same machine setup. On only one schedule are we using forging time, and that is on the welding of two pieces of 0.064.

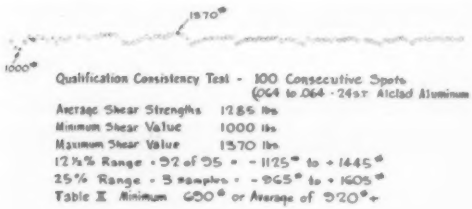
1870#
1000#
Qualification Consistency Test - 100 Consecutive Spots
.064 to .064 - 24ST Alclad Aluminum
Average Shear Strengths 1285 lbs
Minimum Shear Value 1000 lbs
Maximum Shear Value 1370 lbs
12½% Range - 92 of 95 = - 1125# to + 1445#
25% Range - 3 samples - 965# to + 1605#
Table II Minimum 690# or Average of 920#+

Figure 5

Figure 5 gives you an idea as to the consistency which we obtain on our 100 spot-weld qualification test on two pieces of 0.064 Al, which is the largest gage of two-piece aluminum which we have been required to weld. Our average shear strength was 1285 lb our minimum shear value was 1000 lb and our maximum shear value was 1370 lb. Out of 95 samples, 92 were within the $12^1/_2\%$ range, being between 1125 lb minus to 1445 lb plus. The other three samples fall within the 25% range, from a minimum of 965 lb to a maximum of 1605 lb. According to specification MIL-W-6860, Table II, the minimum shear strength requirement is 690 lb; the average shear is 920 lb. Therefore, all these welds were within the range as outlined in the applicable specification. It is interesting to note that at the beginning of the consistency test as shown on the graph, the first third of the welds seemed to rove up and down hill, although the consistency was typical of aluminum spot welds. The last two-thirds leveled off to give a very good picture of what can be done with a single-phase welding machine.

This was our first qualification test and the operator had never before operated a resistance-welding machine of any type. It is therefore possible that the human element presented some variables. As you can see, the maximum value obtained was 1370 lb, although we were allowed a maximum of 1445 lb. Our lowest shear value was 1000 lb. Our average shear values show very good consistency.

The following illustration (Fig. 6) will give you an idea of the nugget size, penetration, indentation and sheet separation which the aforementioned schedules when used will produce. Under specification MIL-W-6860, 0.020 to 0.064 is the maximum of dissimilar thicknesses which can be welded without special dispensation. On all our work we are using 4-in. radius electrodes of Class I alloy, regardless of sheet thickness. If time allows, in the future we will endeavor to make experiments using other radii that the 4 in. to see if

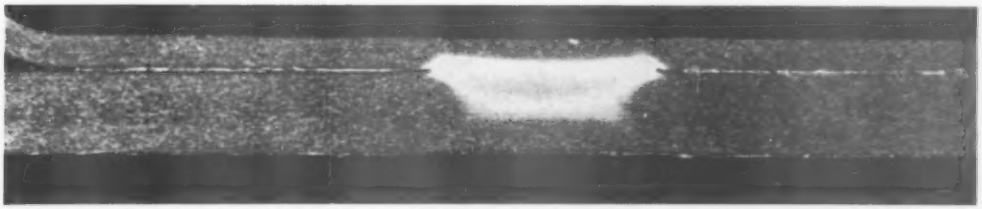

Figure 6

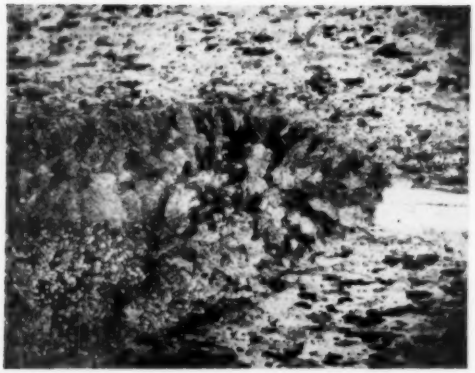

Figure 7

the results continue to be consistent. Indentation is 0.003. Penetration into both the 0.020 and 0.064 is typical for these thicknesses.

Figure 7 shows the weld magnified at 45 times the weld shown in Fig. 6. Just visible in the lower left-hand corner is the cast-aluminum structure surrounded by the typical copper precipitates extending outward from the weld. The middle right shows the Alclad of the two sheets fused. It is interesting to note that the grain refinement from the cast structure outward from the nugget is very gradual.

Figure 8 shows four typical welds of 0.064 and 0.064 Al. You will note that the second weld from the bottom left, shows a small crater at the edge of the cast zone. This particular photo was made up for training purposes within our own organization to show what would happen when tip radius changes due to infrequent tip dressing.

Figure 9 shows two pieces of 0.032 to 0.032 which were made up to show the possibility of catching a machine setting which might possibly be too high. The bottom weld is made according to our weld schedule, while the weld shown at the top side was made with the heat increased one percentage point on the main heat control dial. You can see on the lower right-hand side of the nugget the darkened portion which looks as though the weld were on the verge of spitting.

Figure 10 shows two pieces of 0.020 Alclad which have been welded together. Again on the bottom we have retarded our heat and increased our pressure to give us a cracked weld for instruction purposes. This particular illustration was included because the next figure turned out so well; we thought it would prove interesting

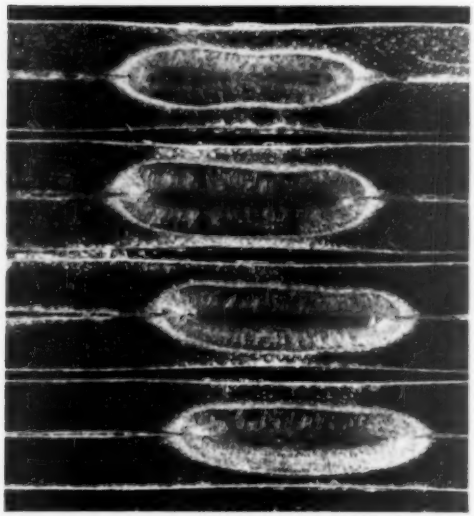

Figure 8

in that it will give an idea how a crack magnified 75 times appears.

Figure 11 is self-explanatory as it shows a typical crater as encountered when settings or tip radii are not correct.

Figure 12 is another illustration at 50 × magnification showing a typical weld nugget with cast zone in the center and with copper precipitate running to the outside. The middle right-hand side of the slide shows that the Alclad is fused.

Figure 13 is an interesting illustration because it shows the fusion of the Alclad ring surrounding the nugget proper, also showing where the fluid aluminum

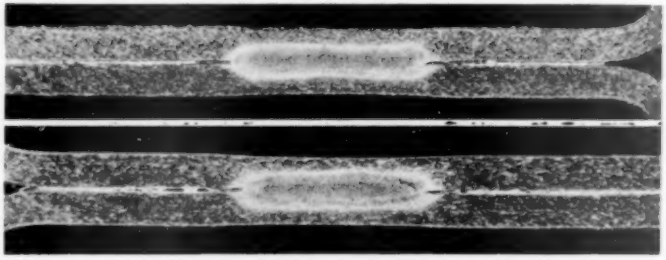

Figure 9

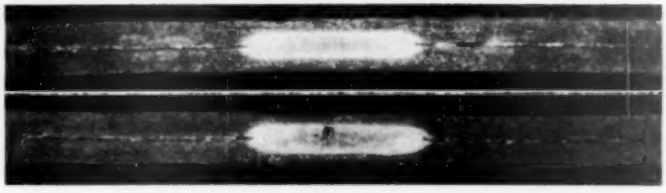

Figure 10

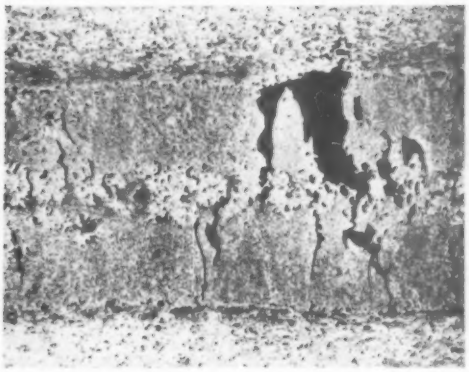

Figure 11

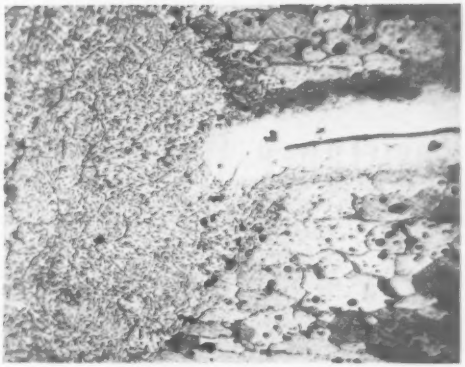

Figure 13

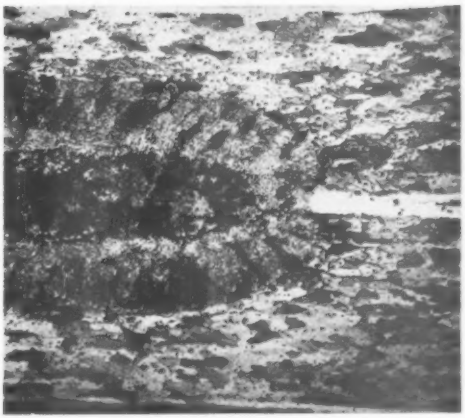

Figure 12

has run into and around the grains in the wrought aluminum.

It must therefore be concluded that:

1. No. 24ST3 Alclad aluminum may be resistance welded to meet MIL-W-6860 Government specification when using single-phase welding equipment with slope control.

2. That cleaning methods are available which will produce consistent surface resistance ranging between 6 and 15 micro-ohms.

3. That maintenance costs will be greatly reduced with single-phase equipment.

4. The initial cost of a single-phase welding machine is approximately one-half that of a 3-phase frequency converter resistance-welding machine.

5. Less operator "know-how" is required for operation of a single-phase welder.

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(*Continued from page 686*)

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Resistance Welding Quality Control

Quality control in jet engine fabrication including chemical analysis and dimension of material equipment, machine settings and testing of completed welds

by Thomas J. Lepito and Robert M. Taylor

RESISTANCE welding is becoming more and more important as a method of fabrication. As a result of the increased application of this method of joining two or more alloy pieces together into a common assembly, there is need of having an accurate means of controlling the quality of the welds produced.

The experience of the writers in this field of quality control has been relative to jet engine fabrication, especially in the burner and exhaust sections of the engine, where many varieties of alloys are joined together by resistance welding. It is to be noted that the following information is based on experience in welding sheet metal and machined forgings and castings having thicknesses in the welded sections varying from 0.025 to 0.110 in. and using electrodes with a tip diameter of spot-type electrode or track width on wheel-type electrode varying from 0.156 to 0.250 in.

The first prerequisite for control of resistance welding is to be certain that the surface finish, chemical analysis, and thickness dimensions of the alloys for the different fabrication jobs are held constant within limits required by specifications; such as the AMS Specifications. These controls can be established by a laboratory check on the chemical analysis of each shipment lot and a dimensional check by an Inspection group.

The second prerequisite for control of resistance welding is to be certain that the welding machine is qualified to weld consistently. This is accomplished by two checks as follows:

1. Using AMS 5510 material, weld and test 100 samples of the thinnest stock to be welded, and 100 samples of the thickest stock to be welded in production.
2. Each production setting will be tested by welding and testing a minimum of 25 samples simulating the joint involved.

In both (1) and (2) 20% of the samples (picked at random) will be macro tested. The remaining spot welds are shear tested and cannot show greater than ±10% variation of strength from the average of 86% of the specimens and ±20% from the remaining specimens. (If aluminum is involved the tolerances shall be ±12% and ±25%.) The spot-weld shear strengths required are those recommended by AWS unless the blueprint requires a specific strength. Seam weld shear tests must always fail in the parent metal.

Note: Spot welds on 0.075 in. or thicker material should have 5 random samples radiographically checked. This has been found necessary as experience has shown that internal defects in spot welds of thicker material tend to run off center of the nugget. The normal macro examination would miss off-center defects and radiographic checks would reveal it.

The next requirement for quality controlling re-

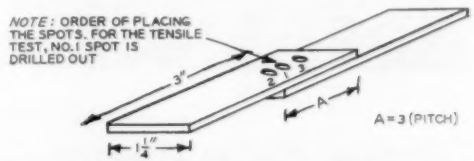

Fig. 1 Spot weld sample (three spots) used when pitch is equal to 1/2-in. or less (to stimulate shuting effect)

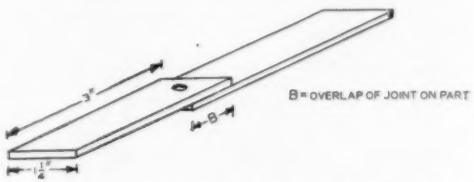

Fig. 2 Spot weld sample (one spot) used when pitch is greater than 1/2 in.

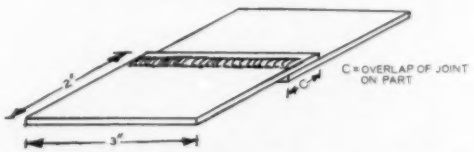

Fig. 3 Seam weld sample, produced by wheel electrodes or overlapping welds of spot electrodes

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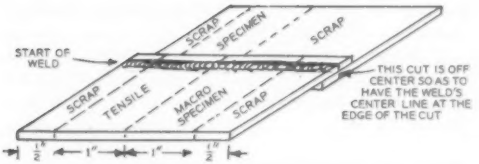


Fig. 4 Dotted lines indicate where to cut (the friction cutting saw has been found quite adaptable for this purpose)

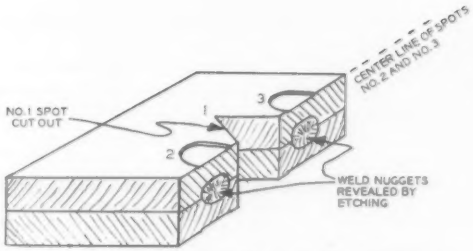
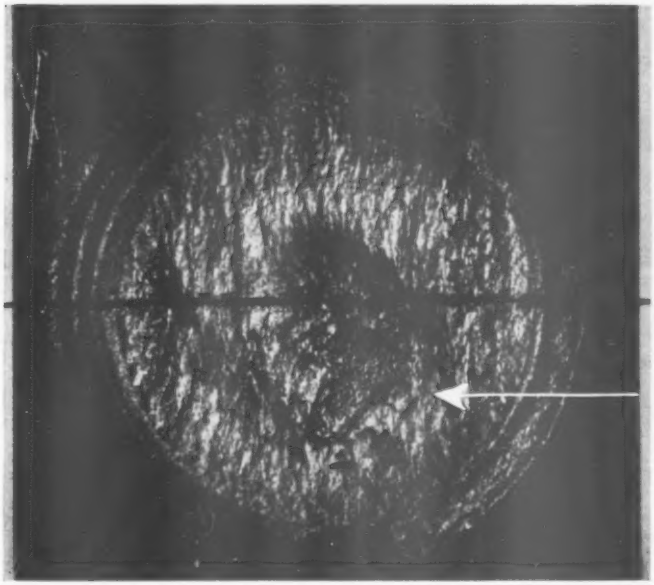


Fig. 5 The three-spot weld test specimen macro

sistance welding is to be certain that the machine setting being used for a particular assembly is producing consistently acceptable resistance welds. The following is a recommended testing procedure for ascertaining these facts:

The quality of the resistance weld is controlled by testing samples of the welding at the start and finish of each production run and initially X-raying a percentage of the parts. A production run is defined by the following restrictions:

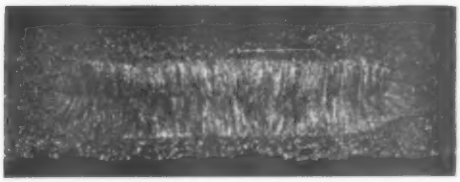
1. One welding machine's output with continuous running.
2. The machine having fixed control settings during that interval.
3. All parts handled in this run must have the same assembly combinations of alloys and dimensions.



Centerline Fracture

Defect shown here is missed in center line of macro (see below) and is cause for rejection

Figure 6



Macro

Figure 7

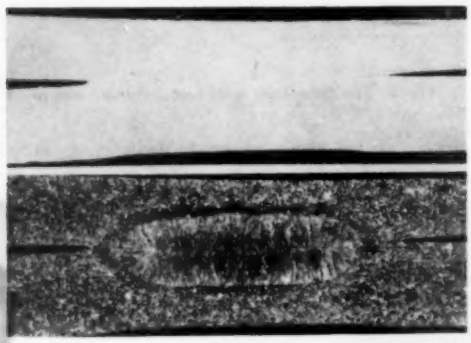
The samples of welding that are tested may be an actual part or a simulated welded joint. The simulated test is made to duplicate the materials, dimensions related to the joints and the welding machine setting. See Figs. 1, 2 and 3 for the three types of simulated test pieces used.

There are two types of resistance welds to be tested, i.e., the seam weld and the spot weld. The spot-weld samples must be prepared in duplicate and the seam-weld samples singularly. There are two phases to the testing; namely, a macro examination and a tensile test. When tensile testing a three-spot weld sample, the No. 1 spot is eliminated and the remaining two spots are shear tested. The resulting breaking load should be equal to or greater than twice the blueprint's spot weld strength requirement per spot. The single-spot weld test piece is tested in shear directly after welding. In tensile testing the seam welds, the sample must be processed as indicated in Fig. 4 and then shear tested. The failure in the weld indicates a rejectable weld. The macro testing of the three-spot weld specimens is performed by removing the No. 1 spot and cutting through the centerline of the No. 2 and No. 3 spots (see Fig. 5). The single spot weld test is cut along its centerline for macro testing. In some joint combinations, the shear tensile tested spot welds will fracture through the

weld nuggets. When this happens, and provided the minimum strength is met, it is practical to interpret the fracture to determine whether the welds are acceptable without having to macro test the representative test piece. In some cases the fracture will indicate rejectable defects that the macro's centerline cut may miss. (See Figs. 6 and 7.)

In macro testing the welds, caution must be taken to be certain that the final cut, polished and etched surface is the true centerline of the weld. See Figs. 8 through 13 of macro standards that may be used for

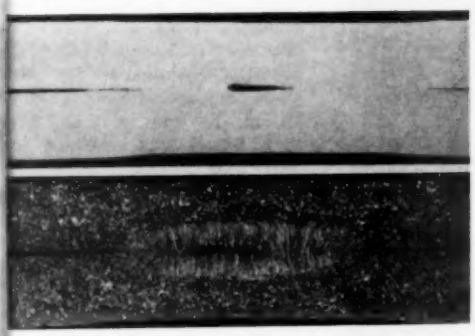
Unetched



Acceptable Etched

Figure 8

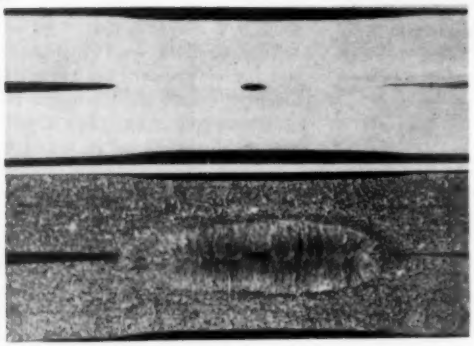
Unetched



Rejectable Etched

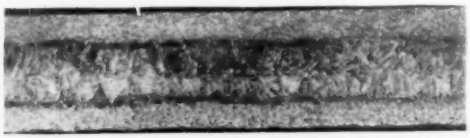
Figure 9

Unetched



Borderline Acceptable Etched

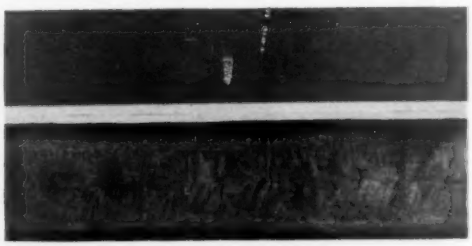
Figure 10



Acceptable Seam weld Mag. 10 × Etched

Figure 11

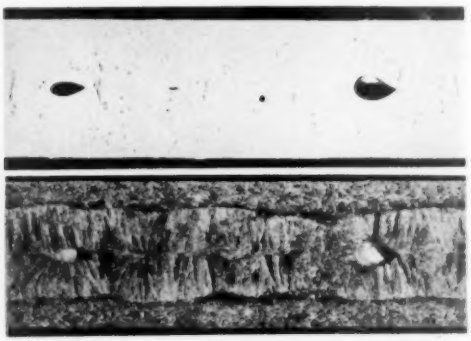
Unetched



Acceptable—Borderline Seam Weld Mag. 10 × Etched

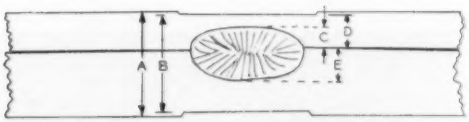
Figure 12

Unetched



Rejectable Seam Weld Mag. 10 × Etched

Figure 13



INDENTATION

% INDENTATION = $\frac{A-B}{A}$ (100)

THE MAXIMUM % OF INDENTATION ALLOWED SHOULD BE 15%

PENETRATION

% PENETRATION = $\frac{C}{D}$ (100) & ALSO = $\frac{E}{D}$ (100)

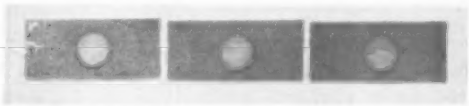
PENETRATION SHOULD BE CONTROLLED WITHIN THE FOLLOWING LIMITS:

(a) MINIMUM = 20%

(b) MAXIMUM = 90%

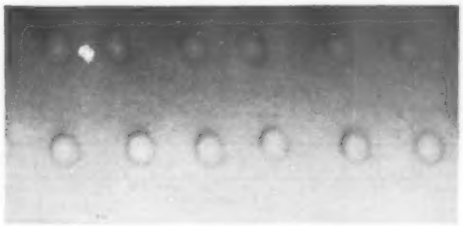
Fig. 14 Weld nugget macro, its measurement and control

determining the usability of a weld. Figure 14 shows how indentation and penetration can be measured and controlled. It has been found that the following etchant is very suitable for macro examination of high-temperature alloys, the more common alloy steels and plain carbon steels:



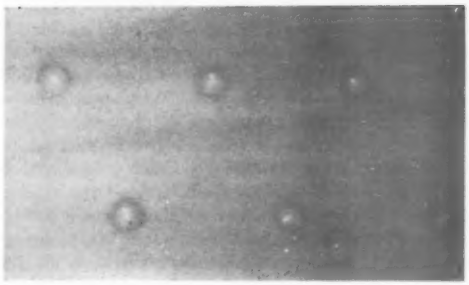
Acceptable

Figure 15



Borderline—Acceptable

Figure 16



Rejectable

Figure 17

Lepito's etchant

100 cc HCl
75 cc H_2O
30 cc HNO_3
15 g $NH_4(SO_4)_2$
250 g $FeCl_3$

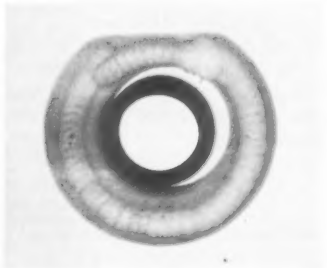
Preparation instructions:

1. Dissolve $NH_4(SO_4)_2$ in the water
2. Dissolve powdered FeCl in the HCl
3. Mix 1 and 2 together and add the HNO_3

A 20 ×Brinnell glass is found suitable for interpretation of the macros.

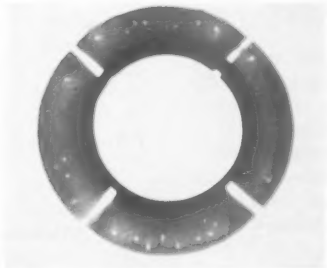
The tensile and macro test results are correlated and a conclusion is reached regarding the acceptability of the test. The macro quality and the minimum strength requirements of a resistance weld will depend on the application of the fabricated assembly. As the writers' experiences have been related to jet engine application, it is felt that the previously indicated quality standards assure a weld that will be stronger and more durable than the original base metal under all conditions.

The final inspection to be made for quality controlling resistance welding is the radiographic inspection on finish welded assemblies to check the forementioned controls. Ten per cent of every production welded lot is usually a good initial percentage to radiograph. After a particular assembly combination has established a good radiographic record, the radiographic requirement may be discontinued. Thereafter, visual irregularities will be X-ray checked. This supplies a check of the correlation between simulated tests and actual parts. See Figs. 15–23 for typical radiographs of acceptable, borderline acceptable, and rejectable resistance welds. However, it must be noted that cold welds, with the exception of welds in aluminum alloys, are not revealed by X-ray inspection. They actually have the same appearance, X-ray wise, as a sound weld. A macro examination is the only positive check for revealing cold welds.



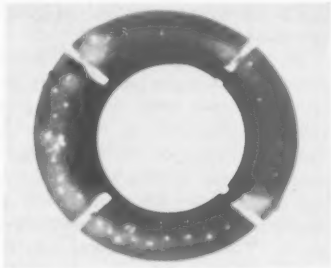
Acceptable

Figure 18



Borderline Acceptable

Figure 19



Rejectable

Figure 20

Acceptable

Figure 21

Borderline—Acceptable

Figure 22

Rejectable

Figure 23

ADDITIONAL FACTS THAT WILL ASSIST IN PRODUCING CONSISTENTLY ACCEPTABLE RESISTANCE WELDS

1. Visible Variables That Can Be Measured and/or Interpreted to Determine the Quality of the Welded Product

A. Pitch variation (spot and seam welds resulting from overlapping spot welds).
B. Temper color or burned surface appearance.
C. Shunting and its affect on the welds.
D. Mushrooming of spot electrodes.

The following are methods of interpreting the above-mentioned variables:

A. Pitch Variation. It is important to control spot-weld spacing or pitch in order to obtain consistent quality of spot welds. A large group of samples of different combinations of alloys having 0.050 in. thickness were spot welded together using a 0.187-in. spot electrode, keeping all dimensions constant except the pitch of the spots. For each alloy combination an optimum setting was established, using a 0.5-in. pitch. Then the additional samples of that alloy combination were spot welded, varying the pitch between 0.2 and 0.9 in. Four samples were made representing each pitch. There are five alloy combinations tested. All the test pieces were radiographed, two of each lot of four were macro tested and the other two were shear tested. The information resulting from these tests has been graphed, see Fig. 24. A study of these results indicates that shunting of current into adjacent spot welds is sufficient to cause a variation in the quality of the weld in 0.050-in. sheet using a 0.187-in. electrode, if the pitch is less than $^1/_2$ in. The AMERICAN WELDING SOCIETY indicates in their tables that 0.031-in. thick sheet may be spot welded with a minimum pitch of $^1/_2$ in. without having any shunting effect. Therefore, on the basis of these facts, it will be permissible to spot weld with single spot test pieces on alloys having thicknesses up to 0.050 in. thick using a 0.187-in. spot electrode with a minimum pitch of $^1/_2$ in. The single-spot weld test piece is much simpler to prepare and test, and should be used whenever it is possible. On parts where the pitch is less than $^1/_2$ in., the spacing of spots should be controlled accurately as any variation will affect the quality of the weld.

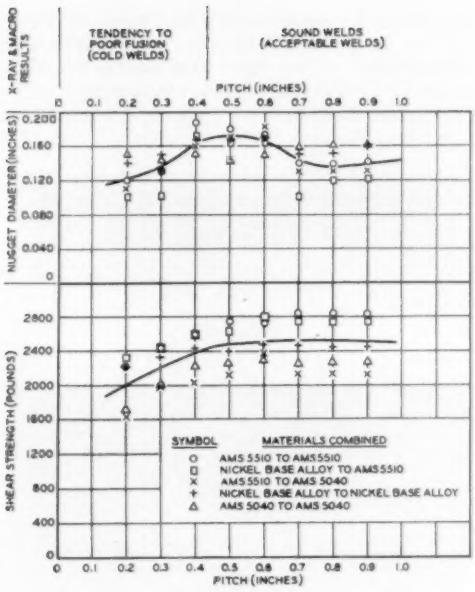


Figure 24

Whenever overlapping spot welds are used to produce a seam weld with an airtight joint, the pitch or spacing control is important. An investigation was conducted varying the pitch on the test pieces and the following rules were established:

Alloy combinations	*Minimum % overlap of the spot weld impression will produce continuous (airtight) fusion*
AMS 5510 to AMS 5510	60
AMS 5510 to Nickel Base Alloy	50
AMS 5510 to AMS 5040	60
Nickel Base Alloy to Nickel Base Alloy	50
AMS 5040 to AMS 5040	50

B. Temper Color or Burned Surface Appearance. Usually a sudden change in the intensity of the temper color indicates a variation in quality of the weld produced. This is especially true in resistance welding of plain carbon steel. A few checks by cutting up these areas and making macro tests will supply the necessary experience whereby the operator will be able to identify bad welds immediately upon their being made and stop production until the cause is determined and eliminated.

C. Current Shunting and Its Effect on Welds. When the electrode contacts some area of the part other than the area being welded, a "cold weld" may result due to the shunting. This is especially true in resistance welding plain carbon steel. Every attempt should be made to eliminate this possibility from existing. If the assembly design is such that it is difficult to weld without contacting the sides of the electrodes with the part, some means of insulation should be used. There are many possible forms of insulation; for example:

1. Insulating paint or lacquer.
2. Rubber gaskets.
3. Cambric insulation.
4. Micarta.
5. Lucite

D. Mushrooming of Spot Electrodes. Initially it was felt that electrode growth via mushrooming would decrease the intensity of the heat; thereby producing a "cold weld." However, this has not proved true. It has been found that electrode growth may be ignored as long as the testing sequence is carried out as explained in this article. Actually the only time electrode growth will cause difficulty is where the expanded tip may cause shunting with some other area of the part being welded. As the electrode tip mushrooms it tends to develop a radius on its tip which causes a concentration of a given amount of heat at the center of the electrode contact. This electrode tip rounding appears to counteract the increased surface area of contact caused by the mushrooming of the electrode tip. There are practical limitations of electrode tip mushrooming and they will necessarily depend on the type of job that is being done.

II. Intermediate Tests

When a resistance weldment job is continuously running an intermediate test check will be made as frequently as deemed necessary to test consistency of quality of parts produced. This intermediate test will only require a macro check. At the completion of the production run a "close out" test of macro and tensile will be made.

III. Rate of Pulling Tensile Tests and Its Influence on Spot Weld Strengths

It has always been important in tensile testing stainless steels to require a slow fixed rate of pulling. For production testing purposes, it is realized that the slow rates of pulling used on stainless steels by material testing laboratories is much too slow to be applied to testing production spot-resistance welds. Tests were run to determine the influence of varying rates of pulling on spot-resistance welds. Sixty-five duplicate single-spot welded 18–8 stainless steel samples were made on one welding machine fixed setup. These were shear tested in lots of five at varying rates of pulling, starting at 0.05 in. per minute and increasing up to 2.5 in. per minute. The test results of each lot of five, having the same rate of pulling, were averaged and then plotted against the rate of pulling. Note Fig. 25. The lower plot on the graph indicates the variation of strengths within each group which were pulled at one constant rate of speed. The graph shows that the rate of pulling between 0.05 and 2.5 in. per minute causes only a 2.6% strength variation which is considered negligible for production testing. These results indicate that the more rapid pulling rates may be used in testing and controlling production resistance spot welds of work-hardenable alloys.

IV. Reworking and Correcting of Rejectable Resistance Welds

There are two possible causes of a weld rejection. They are: lack of fusion (cold weld) and porosity and cracking (hot weld). These conditions were determined by the shear, macro and/or X-ray testing.

In the three types of resistance welding—spot welding, seam(overlapping spot welds) and seam (wheel electrode overlapping welds)—it has been found through investigation that the following repairing may be safely accomplished:

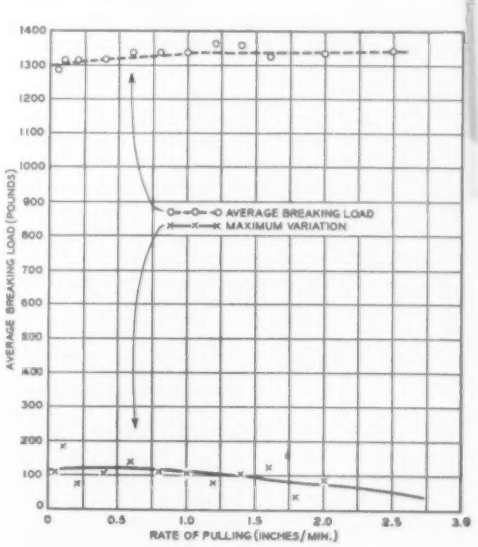


Figure 25

A. Spot Welds. Spot welds of all alloy combinations that have a rejected cold weld may be easily and soundly rewelded. This is accomplished by establishing an acceptable weld setting on new test pieces and rewelding directly over old rejected welds.

If a rejected weld was a hot weld the same procedure for rewelding may be applied but the next larger size electrode must be used.

B. Seam (Overlapping Spot Welds). All alloy combinations that have had this type of seam weld rejected for cold weld may easily and soundly be rewelded. This is accomplished by establishing an acceptable weld setting on new test pieces and rewelding directly over the previously rejected weld.

If this type of seam weld was rejected as a hot weld (excessive cracking and porosity), the weld may be repaired, with the exception of plain carbon steel, in the same manner that a cold weld was repaired. However, when plain carbon steel is involved in the rejected hot weld joint, a weld setting that would produce a continuous fusion of shallow penetration (tendency to a cold weld) should be used. This is necessary as it has been found that when rewelding hot welds of plain carbon steel with a standard acceptable weld setting, the resultant weld tends to have more porosity and cracking rather than eliminating it.

C. Seam (Resulting from Wheel Electrodes Overlapping Welds). All seam (wheel electrodes) welds that are rejected because of a hot or cold weld may easily be rewelded. A new machine setting that would normally produce an acceptable weld is used to reweld the rejected weld.

All of the above mentioned rewelding is the result of extensive investigation of various alloy combinations. In rewelding both types of seam weld (resulting from spot and wheel electrodes) caution must be taken to be certain that the resulting indentation has not increased beyond allowable limits (15% max.).

RÉSUMÉ

A. The following requirements are essential for obtaining quality control of resistance weldings:

1. The test pieces must simulate the parts as to material involved, surface finish, heat treatment and dimensional make-up of the joint (edge distance, thickness ± 10%, etc.).

2. The welding machines are proved to produce consistently acceptable welding quality on each production schedule used.

3. Checking the proper simulation of the above controls by radiographing 10% of each production lot until records indicate consistency in part results.

B. The knowledge of the following facts will greatly aid in the production of sound acceptable resistant welded joints.

1. Visible indications that should be controlled:

(*a*) Pitch Variation
  (1) Spot welds—Must be controlled closely when the pitch is less than $^1/_2$ in.
  (2) Seam (overlapping spot welds)—A minimum overlap of 60% of each spot weld impression using a good setting will guarantee continuous fusion and air-tight joint.

(*b*) Temper color variations should be watched for and such variation should be analyzed so they can be interpreted.

(*c*) Means should always be taken to eliminate any possible shunting of the electrode against the parts in areas other than the areas being welded.

(*d*) Mushrooming of electrodes need be limited only in so far as their practical application is concerned (relation to shunting), as long as each production run is bracketed with a simulated or part test check.

2. The variation of the rate of pulling tensile tests of spot welds has very little influence on the resultant strength of the spot weld. For production testing, the rapid rate of pulling at approximately 2.5 in. per minute is safe and accurate.

3. Resistance welds that have been rejected may easily be corrected.

(*a*) Spot welds may be rewelded by superimposing new welds on top of the rejected welds as long as the indentation will permit (max. 15%).

(*b*) Seam welds may be rewelded by welding over the rejected welds with an acceptable new weld machine setting. The one exception is rejected hot seam weld on any carbon steel application when the seam weld results from overlapping spot welds. This exception may be rewelded by using a semicold weld (shallow penetration with continuous fusion).

Flame Hardening Turret-Ring Ball Races

Fixture and process for successfully flame hardening ball races of vehicular turret rings in vertical position developed at Detroit Arsenal

by B. A. Schevo and Z. J. Fabrykowski

INTRODUCTION

IT IS necessary to harden the ball races of vehicular turret rings that are used for military service. At one time these surfaces were hardened in an angular position at the Detroit Arsenal. This method was not entirely satisfactory and resulted in difficulties in control of the pattern. After some experimentation, the Welding Section of the Materials Laboratory developed a fixture and a process for successfully flame hardening these rings in a vertical position.

This article describes the fixture and the procedure used for flame hardening of turret rings for the T-47 vehicle. The same principles are applicable to rings used for other purposes.

GENERAL FIXTURE DESIGN

A general view of the fixture is shown in Figs. 2 and 3. Essentially, the fixture consists of a steel framework to which are attached the necessary positioning and working units. The ring is friction driven by two shaped composition rollers. Two additional adjustable vertical rollers support and position the ring at its top. A special hardening head with auxiliary openings for quench water is located on the left side. This head is supported horizontally 90 deg from the top of the ring. A tank and copper tubing supply cooling water on the right side of the ring. The lower drive rollers are mounted above an open tank. This tank's principal function is to catch quench and cooling water.

CHEMICAL ANALYSES OF TURRET RINGS

The following analyses are representative of the composition of the T-47 rings. These analyses conform to an FS4140 steel.

Element	*Retainer ring*	*Lower ring*	*Upper ring*
Carbon	0.36	0.40	0.42
Manganese	0.82	0.78	0.88
Phosphorus	0.030	0.028	0.030
Sulfur	0.032	0.033	0.042
Silicon	0.28	0.23	0.31
Chromium	0.98	0.99	0.95
Nickel	0.10	0.12	0.07
Molybdenum	0.20	0.25	0.21

HANDLING OF TURRET RINGS

Rings must be handled with care when positioned into the fixture. Also, they must be stored in a horizontal position separated by wooden spacers. The ball races are left in the as-hardened condition. A light coating of rust which forms due to the water coolant is removed in a subsequent buffing operation. Grinding is not performed on the ball races after the hardening operation.

PRELIMINARY TESTS

Preliminary tests were performed on small sections to arrive at the desired shape and depth of the hardened zone. All the variables were recorded as shown in Fig. 1. The procedure developed was then applied to a full ring which was subsequently sectioned at 90-deg intervals and examined for consistency of pattern and hardness. The results were found to be satisfactory.

Actual flow of oxygen and acetylene required for the hardening operations is listed in Table 1.

Table 1—Gas Flow

	Gage pressure, psi	*Flowmeter reading*	*Actual flow, cfh*
Lower ring assembly			
Acetylene	14	90	107.8
Oxygen	15	69 3/4	124.07
Upper ring			
Acetylene	13 3/4	94	112.87
Oxygen	15	73	132.31

MACHINE SETUP AND HARDENING PROCEDURE

From data accumulated during preliminary testing, the equipment and hardening procedures were de-

B. A. Schevo and Z. J. Fabrykowski are Chief, Welding Section, Laboratories Division, and Chief, Welding Section, Research and Engineering Division, respectively, Detroit Arsenal.

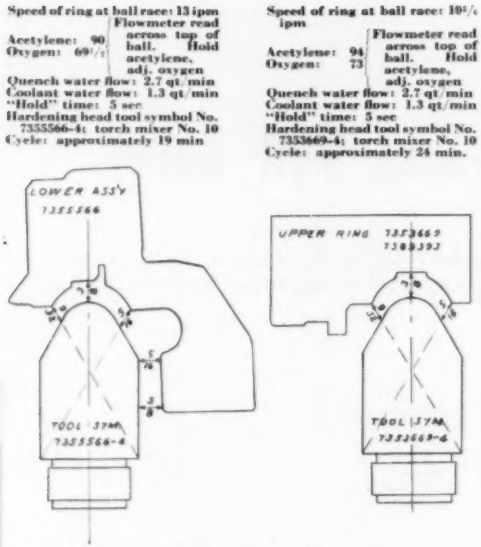

Speed of ring at ball race: 13 ipm
Flowmeter read across top of ball. Hold acetylene, adj. oxygen
Acetylene: 90
Oxygen: 69½
Quench water flow: 2.7 qt/min
Coolant water flow: 1.3 qt/min
"Hold" time: 5 sec
Hardening head tool symbol No. 7355566-4; torch mixer No. 10
Cycle: approximately 19 min
LOWER ASS'Y 7355566
TOOL SYM. 7355566-4
Speed of ring at ball race: 10½ ipm
Flowmeter read across top of ball. Hold acetylene, adj. oxygen
Acetylene: 94
Oxygen: 73
Quench water flow: 2.7 qt/min
Coolant water flow: 1.3 qt/min
"Hold" time: 5 sec
Hardening head tool symbol No. 7353669-4; torch mixer No. 10
Cycle: approximately 24 min.
UPPER RING 7353669
TOOL SYM. 7353669-4

Fig. 1 Alignment of hardening head to ball race

Fig. 2 Hardening fixture with upper ring 7353669 mounted in position

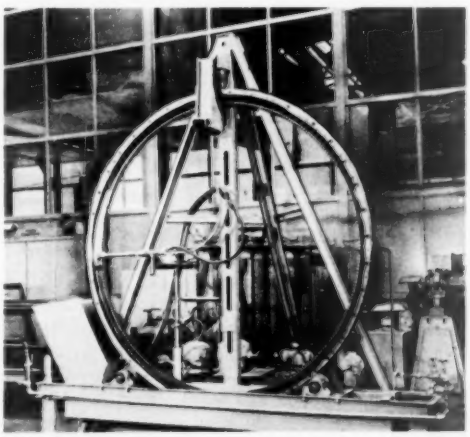


Fig. 3 Hardening fixture with lower ring assembly 7355566 mounted in position

veloped and standardized. The equipment settings are listed in Fig. 1. The details of the hardening cycle procedure are given below:

1. A turret ring is mounted on the two drive rollers of the fixture as shown in Fig. 2.
2. Ring rotation is accurately determined with a stop watch.
3. The hardening head is ignited and the acetylene and oxygen adjusted to the proper flowmeter readings. The acetylene flow is adjusted accurately; the oxygen flow is then adjusted to produce a neutral flame. Quench water must be flowing through the hardening head immediately after the torch is lit, otherwise damage by overheating may result.
4. The hardening head is set into the ball race of a ring before the ring is put in motion.
5. After a 5-sec "hold" time, to permit the ball race to come up to the proper heat-treating temperature, the ring is set in motion.
6. The coolant water, which is diametrically opposite the torch, is set flowing after the ring is in motion.
7. The flame-hardening cycle is completed when the trailing neutral flame of the hardening head impinges upon the previously hardened area after traversing a continuous progressive path of one complete revolution of the ring.
8. The hardening head, with the quench water flowing, is permitted to remain in the ball race for about one-quarter of a revolution after the flame is shut off.

RESULTS AND DISCUSSION

The flame-hardening fixture with an upper ring and with a lower ring assembly mounted in position for hardening may be seen in Figs. 2 and 3, respectively. It is important that the torch be adjusted so that the hardening head enters the ball race on the horizontal diameter of the ring.

Figures 4 and 5 show the hardening heads with the adjustable roller followers set into the ball races. An adjustable spring, fastened to the torch body mount, holds the follower in contact with the ball race, thus producing a constant head-to-ring relationship.

Figures 6 and 7 show an ignited hardening head with quench water flowing. The quench water is adjusted to provide maximum flow without interference

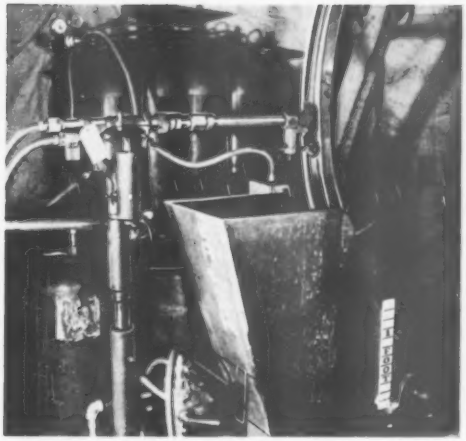


Fig. 4 Flame-hardening torch and supporting assembly

with burning of the head because excessive pressure causes the quench water to splash onto the flame ports. A close-up of a flame-hardening head in operation is shown in Fig. 8.

The back side of the hardening fixture, illustrated in Fig. 9, contains the drive mechanism. The worm gear reducer is at the left, the hydraulic transmission at the right center. A water tank is suspended from the main horizontal frame members. This tank is of sufficient capacity (76 gal) to quench and cool two turret rings and provide all the water used for cooling operations. The water pump may be seen in Fig. 5. It is a precaution taken to prevent burning of a ring should a failure occur in the main water line.

Ring travel was measured circumferentially at the innermost part of the ball race and timed with a stop watch.

Extinguishing of the torch at the completion of the hardening cycle must be accomplished with care. It was found that an overlap of $^1/_2$ in. produced optimum

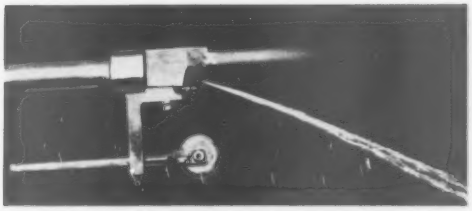


Fig. 6 Flame-hardening head for lower ring assembly 7355566

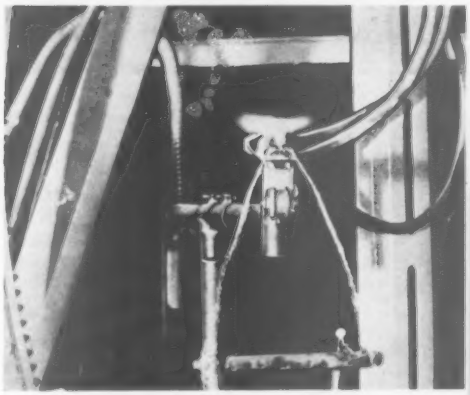


Fig. 7 Head-on view of hardening head (water pressure reduced)

results. Excessive overlapping may lead to warping of the ring. Stopping too soon leaves an area in the unheat-treated condition. The hardening cycle is completed when the trailing neutral flame impinges upon the area $^1/_4$ in. beyond that previously hardened by the leading neutral flame. The leading flames are those on the upper side of the flame-hardened head.

The flame-hardened patterns obtained using the procedures outlined herein are shown in Fig. 10. The hardness of the retainer ring was maintained at a shal-

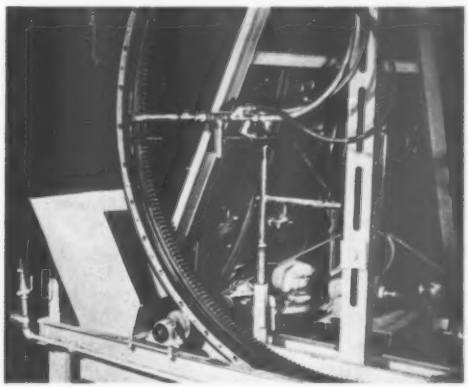


Fig. 5 Water pump and drive mechanism torch set up for lower ring assembly 7355566

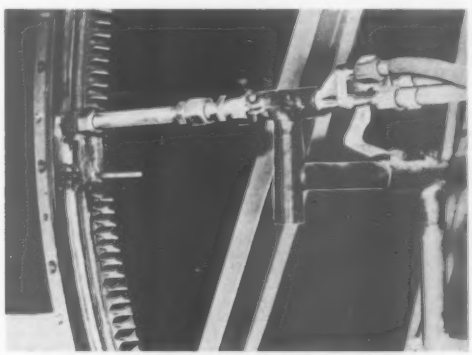


Fig. 8 Hardening head in operation in lower ring assembly 7355566

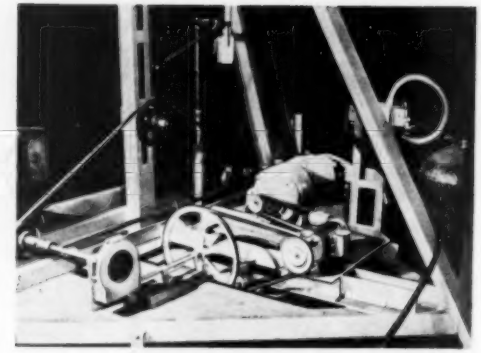


Fig. 9 Drive mechanism

lower depth than the other ball races to prevent hardening beyond the grease groove radius. It was believed this would have caused excessive distortion of the ring since the lower and retainer rings were hardened in assembly. The hardness indicated at the grease groove (see Fig. 10) was the result of heat entrapment in the center of the ball race.

Dimensional checks taken before and after flame hardening of the turret rings are listed in Tables 2 and 3. Figure 11 indicates the locations on the rings at which the diameters were measured. Due to the fact that there was a shrink in dimension, as measured across balls, after the flame-hardening operation, machining

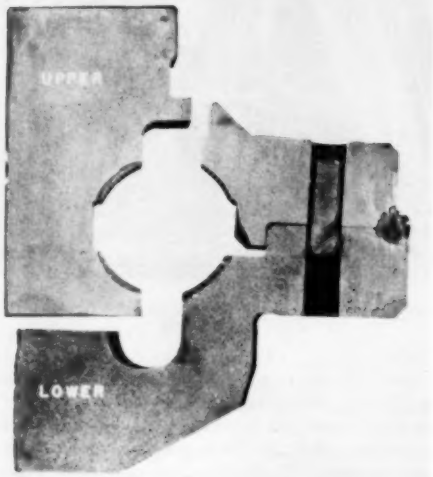


Fig. 10 Photomacrograph showing depth of flame-hardened zone

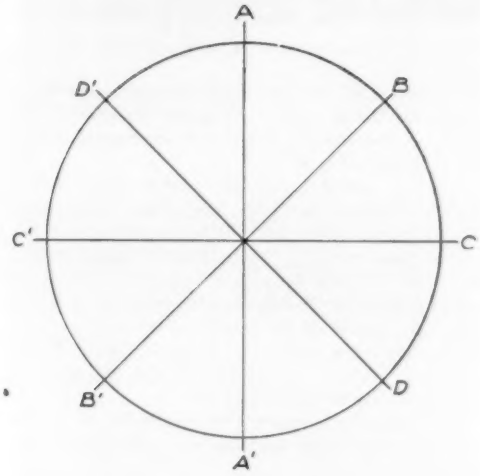


Fig. 11 Actual dimension locations

Table 2—Measurements, Upper Ring 7353669

Position	*Dimension location*	*In machine*	*Before heat treatment*	*After heat treatment*	*Change in dimension due to heat treatment*
		No. 778			
A-A¹	OD ring	76.2485	76.245	76.237	....
A-A¹	Across balls	77.246	77.247	77.237	....
B-B¹	OD ring	76.248	76.237	76.231	....
B-B¹	Across balls	77.246	77.238	77.241	....
C-C¹	OD ring	76.249	76.244	76.263	....
C-C¹	Across balls	77.246	77.246	77.246	....
D-D¹	OD ring	76.248	76.248	76.267	....
D-D¹	Across balls	77.246	77.245	77.232	....
Avg	OD ring	76.248	76.243	76.249	+0.006
	Across balls	77.246	77.244	77.239	−0.005
		No. 781			
A-A¹	OD ring	76.249	76.245	76.244	....
A-A¹	Across balls	77.2435	77.244	77.236	....
B-B¹	OD ring	76.249	76.249	76.244	....
B-B¹	Across balls	77.243	77.246	77.232	....
C-C¹	OD ring	76.2485	76.247	76.246	....
C-C¹	Across balls	77.2425	77.239	77.240	....
D-D¹	OD ring	76.2485	76.236	76.240	....
D-D¹	Across balls	77.242	77.240	77.236	....
Avg	OD ring	76.2487	76.2442	76.2435	−0.0007
	Across balls	77.2427	77.2422	77.2360	−0.0062

Table 3—Measurements, Lower Ring Assembly 7355566

Position	Dimension location	In machine	Before heat treatment	After heat treatment	Change in dimension due to heat treatment
		No. 540			
A-A[1]	Across balls	74.7773	74.7748	74.7775	....
B-B[1]	Across balls	74.777	74.7762	74.7755	....
C-C[1]	Across balls	74.778	74.7836	74.7603	....
D-D[1]	Across balls	74.7783	74.7765	74.7667	....
Avg	Across balls	74.7776	74.7778	74.770	−0.0078
		No. 541			
A-A[1]	Across balls	74.781	74.776	74.7741	....
B-B[1]	Across balls	74.7812	74.7708	74.7757	....
C-C[1]	Across balls	74.7821	74.784	74.7685	....
D-D[1]	Across balls	74.7822	74.7895	74.7734	....
Avg	Across balls	74.7816	74.7801	74.7729	−0.0072

was performed to the upper dimensional limits. This produced flame-hardened rings within the tolerance limits.

The measurements taken in the machine were performed immediately after the last machine operation on the ball race and while the rings were still in their "clamped down" position. The upper rings and lower ring assemblies were placed in a pot chuck for dimensional checks across the balls. The outside diameter of the upper ring was measured in the "free state."

RECOMMENDATIONS

To produce flame-hardened ball races of desired hardness and hardened pattern it is essential that trial runs be performed and cross sections of the rings examined. Only by this manner can positive results be produced by the flame-hardening operations. Cognizance must be taken of the fact that any engineering changes subsequent to the establishment of flame-hardening procedures may effect the results produced by such hardening.

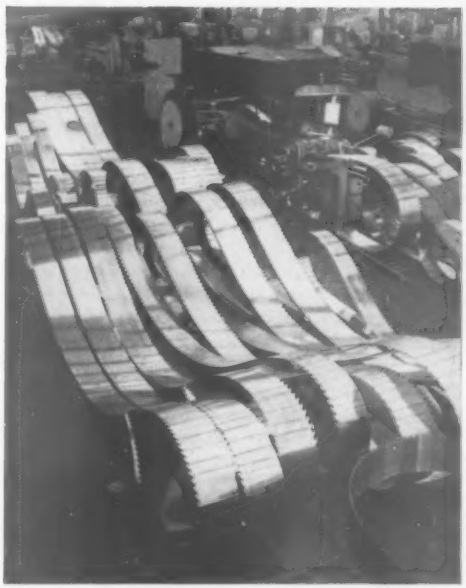
PRACTICAL WELDER AND DESIGNER

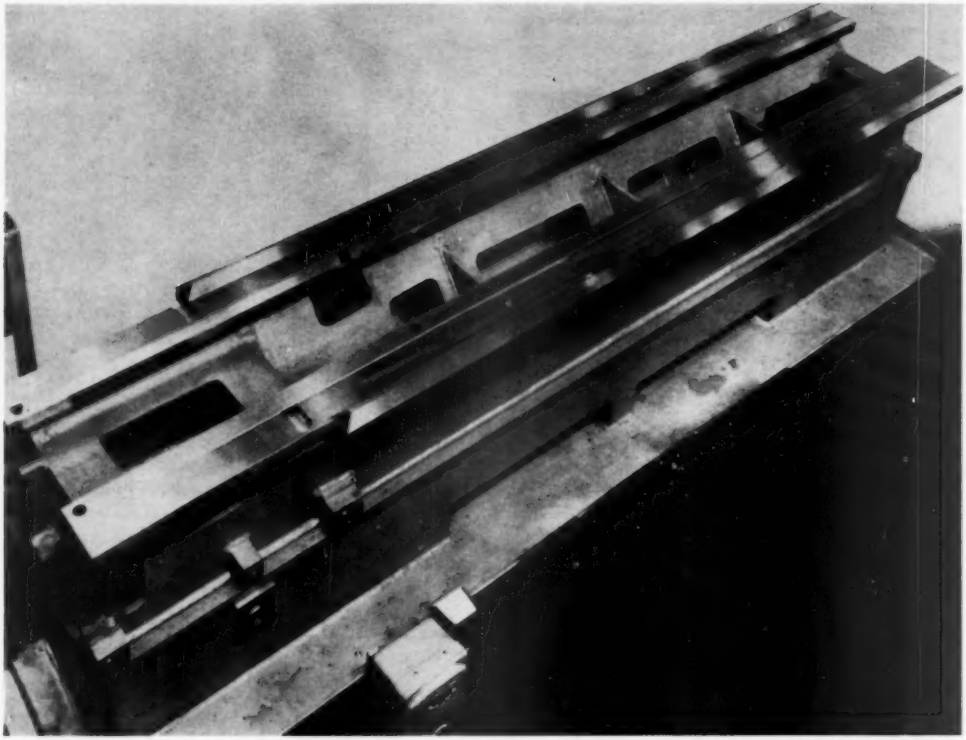
A Cascade of Band-Saw Blades

THESE recently completed 50-ft endless band-saw blades, shown awaiting shipment from the Simonds Saw and Steel Co., Fitchburg, Mass., were joined together with General Electric atomic-hydrogen welding equipment.

According to Simonds engineers, a 50-ft band-saw in use travels at express-train speed and bends as often as 440 times a minute. Thus, even normal operation subjects it to the severest test and any weakness in steel or joints will cause the saw to snap and fly apart.

To avoid this, Simonds makes its own saw steel from selected melting stock and alloys. In joining the band saws, some as long as 60 ft and as wide as 16 in., Simonds uses its own specially made filler rods in conjunction with GE atomic-hydrogen welding. This method, the engineers said, has been found to be the best process yet tried, and they have been using it successfully for the last seven or eight years. During that period, not a single report has been received of a weld breaking while a saw was in operation.





Photos Courtesy the Lincoln Electric Company

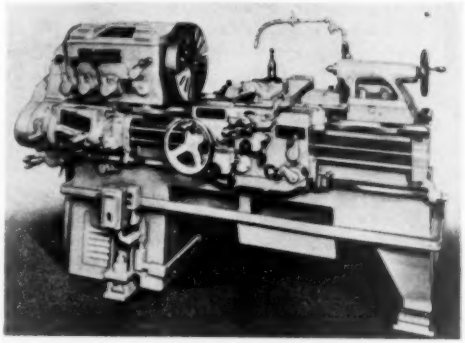
Part of welded steel bed for a welded lathe

Welded Lathe

AN INTERESTING solution has been made by the Reed-Prentice Corp. of Worcester, Mass., to the problem of providing precision machinery for operation under shipboard conditions of floor movement and gunfire shock. The company has recently completed an engine lathe with a welded steel bed and welded steel supports. Tests were made on the lathe without prepared foundations, leveling or anchoring. The unit thus is also highly adaptable to land as well as ship installations since it can be relocated frequently and readied for productive work without delay.

The problem of maintaining precision and accuracy under extreme conditions was solved: (1) by the use of welded steel in the bed, providing rigidity greatly in excess of a comparable cast-iron bed; (2) by designing the supporting members to absorb and dissipate forces causing deflection. The bed design is an adaptation of the principle of the triangle; it is a welded unit of back and front walls connected by diagonal plates, reinforced by vertical cross plates.

The supports are steel legs which rest on three cushioned ball and socket bearings. In addition to supporting and anchoring the bed, they also block transmission of motion and strains to the bed. Cushions absorb shock.



Completed lathe

How to Cut Heavy Steel Sections

by G. E. Kabacy

Oxy-acetylene cutting is the fastest method for cutting steel. This article tells you how to cut heavy steel sections with a hand-cutting blowpipe.

FIRST HEAT SPOT AT START

Whenever you cut heavy steel sections, first heat a spot at the start of the line of cut (Fig. 3). Point the

G. E. Kabacy is connected with Linde Air Products Co., Buffalo, N. Y.

Fig. 1 Set up the work so that the cutting can be done conveniently. Place a length of angle iron or a similar guide on the work to act as a "rest" for the blowpipe

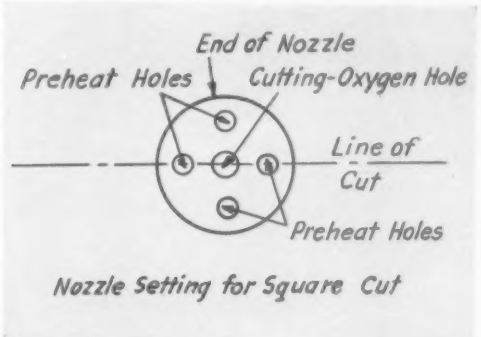


Fig. 2 Then select the correct nozzle for the job. Set it in the blowpipe so that the two preheating jets will fall directly on the line of cut

blowpipe slightly away from the work. When the spot on the top surface starts to melt, press down the cutting-oxygen lever. Then turn the blowpipe into the work so that the nozzle is straight up and down.

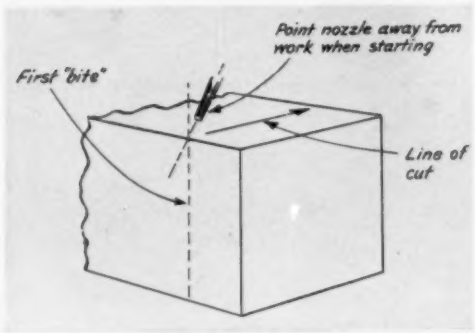


Fig. 3 Light the blowpipe, and heat a spot on the top surface at the start of line of cut

Fig. 4 Point the blowpipe slightly away from the work while you heat the spot. When the spot melts, turn on the oxygen

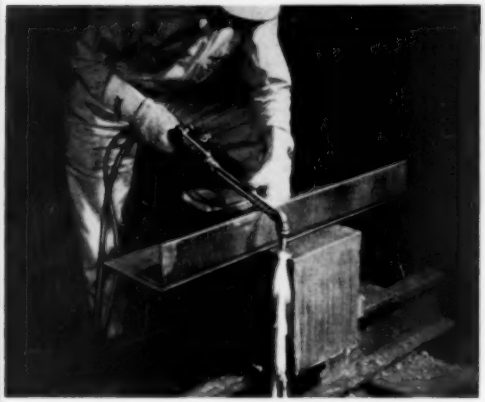


Fig. 5 Now straighten the blowpipe. Nozzle is straight up and down. When the cut goes through the work begin moving the blowpipe

Fig. 6 Keep the nozzle straight up and down, and keep it resting on the angle iron. Move the blowpipe along the line steadily

Fig. 7 Do not move along too fast. Be sure that the cut is going straight through the work

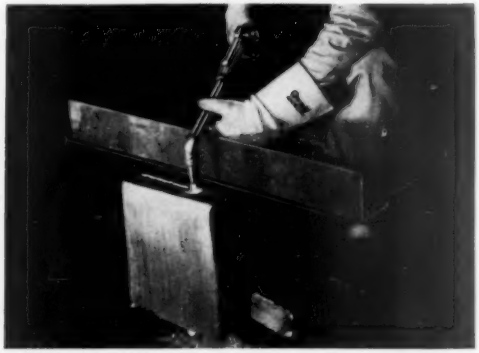


Fig. 8 Swing the blowpipe slightly forward as you move along the cut. The blowpipe pivots on the angle iron

Fig. 9 Roll the hand that supports the blowpipe to keep the "pivoting action" constant. Keep the blowpipe moving smoothly—never stop during the cut

Fig. 11 Here is the finished cut. By moving the blowpipe at a smooth, steady rate, the cut surface is smooth

Fig. 10 The cut should come through the bottom surface of the section first, and start up

THEN CUT

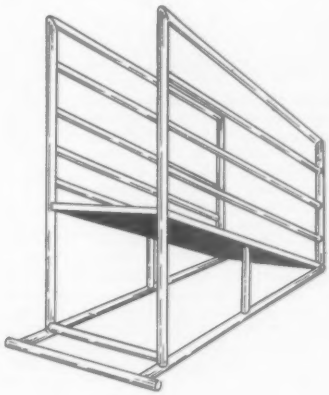
As soon as the cut goes all the way through the work, begin moving the blowpipe along the line of cut. That's about all there is to it. Of course, it takes a little practice to get smooth cuts in heavy sections.

The following step-by-step procedure shows how to cut a heavy steel section. The following figures show how to cut through 120 sq in. of steel in 120 sec.

Loading Ramp

by F. C. Geibig

THE frame and rail of this loading ramp can be made from 2- and 4-in. pipe. Cut and weld to the proper length to get the height and pitch you want. Heavy planks make the incline floor.



F. C. Geibig is connected with Linde Air Products Co., Newark, N. J.

the AMERICAN WELDING SOCIETY

activities • related events

Shortage of March and April 1952 Issues

It is requested that any members of the SOCIETY who have no further need for the March and April 1952 issues of THE WELDING JOURNAL to kindly mail their copies to the SOCIETY, 33 W. 39th St., New York 18, N. Y. There exists a critical shortage of these issues. Postage on mailing will be guaranteed by this office.

Rules for Welding Piping in Marine Construction—Ferritic Alloy Steels

The recent trend to greater pressures and temperatures for marine piping has led to the use of alloy steel piping. This required revision of existing rules and regulations governing the welding of piping, which were intended for carbon steel only. The AWS Marine Committee has just completed the *Rules for Welding Piping in Marine Construction—Ferritic Alloy Steels*, which contains the requirements for joint design, electrodes, welding procedures, postheat, preheat, stress relief and testing of welded ferritic alloy steel pipe joints. Included is a radiographic standard for evaluating weld quality, as well as nondestructive test requirements.

These Rules represent requirements which are acceptable to all the Enforcement Agencies in the shipbuilding industry.

Copies are available at 50¢ each from AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

New Sustaining Member

The **Ingalls Shipbuilding Corp.** pioneered in the construction of all-welded ships. With two shipyards, one at Decatur, Ala., and the other at Pascagoula, Miss., both inland and seagoing marine activities are served. Clients have included nearly all the major steamship lines of this country, many inland waterway operators and such Government agencies as the Navy, Maritime Administration, Corps of Engineers and Army Transportation Corps. Ingalls has also built ships for foreign account, notably for Latin American government and private interests.

Monro B. Lanier, President, The Ingalls Shipbuilding Corp. is Sustaining Member Representative.

Standard Rules for Field Welding of Steel Storage Tanks

A new, 1952 edition of the *Rules for Field Welding of Steel Storage Tanks* has just been issued by the AMERICAN WELDING SOCIETY. This old, recognized and widely used standard for the first time now includes provisions for the use of automatic welding in the fabrication of storage tanks for storing liquids at not over 15 psi gage pressure.

The existing Rules have been revised to cover the qualification of welding procedures and welding operators for automatic welding and related requirements throughout.

Provision is also made for the use of low-hydrogen electrodes for manual arc welding. The requirements for manual welding have been reviewed and brought up to date as necessary.

Copies may be obtained, at 50¢ each from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Executive Committee Meeting

The second meeting of the Executive Committee of the AMERICAN WELDING SOCIETY for 1951–52 was held in Room 608 of the Engineering Societies Bldg., New York, N. Y., on Thursday, June 12, 1952, at 10:00 A.M.

The following attended.

Members: Chairman C. H. Jennings, F. L. Plummer, E. R. Seabloom, L. C. Bibber and H. E. Rockefeller.

AWS Staff: J. C. Magrath, *Secretary*, and F. J. Mooney, *Assistant Secretary*.

Guests: H. R. Morrison, Chairman, Convention Committee; C. D. Evans, Chairman, and S. A. Greenberg, Secretary, Technical Activities Committee; O. B. J. Fraser, Chairman, Special Committee on Membership Classification and member of the Board of Directors.

Convention Committee Report

H. R. Morrison, Chairman of the Convention Committee, 1951–52 year, presented a written report. Mr. Morrison called upon Mr. Mooney to report on a meeting of the Housing Committee held in Philadelphia, Pa., on Thursday, June 5, 1952. Mr. Mooney advised that of the requests received from members of the SOCIETY, approximately one-half will be accommodated at the Bellevue-Stratford Hotel and the balance will have to be assigned to other hotels located in the city of Philadelphia. Assignment of the balance will be made by the Philadelphia Convention and Visitors Bureau. The Assistant Secretary advised that the Philadelphia Section, responsible for the dinner, had, after deliberation by all concerned at its meeting, decided that it would be best to hold a high-class dinner. For this a good meal would be served, accompanied by good entertainment, both of which could be widely and justly publicized beforehand.

Manufacturers Committee Report

The Chairman advised that a meeting of the Manufacturers Committee was called by him, acting as pro tem Chairman, on Tuesday, June 10, 1952, in New York. In view of the fact that the various interested Committees, on the basis of previous approval of their recommendations by the Board of Directors, have suggested proceeding with plans for an AWS fully sponsored spring activity in Houston, Tex., in 1953, and similar action by the Manufacturers Committee, upon motion, duly seconded, the Executive Committee approved of the Secretary proceeding with the preliminary arrangements for holding a spring activity of AWS in the southwest in 1953.

Appointment of Membership Chairman

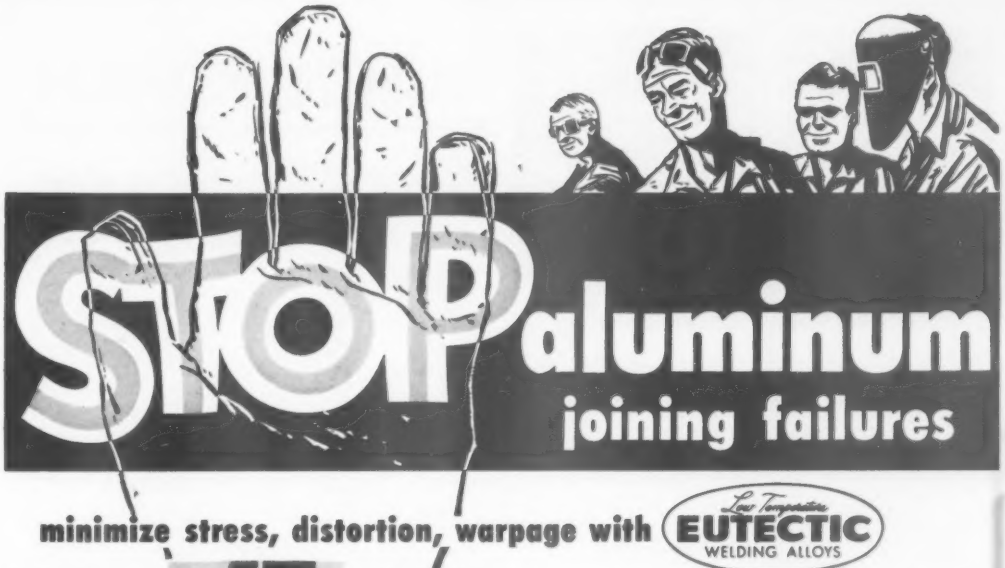
Chairman Jennings advised that, as President, he was appointing R. L. Townsend to the Office of Chairman of the National Membership Committee, 1952–53 year, subject to the approval of the Board of Directors.

Action: Upon motion, duly seconded, the Executive Committee so approved.

Special Committee Appointment

Chairman Jennings recalled to the Executive Committee that the Board of Directors had approved the organization of a Special Committee for the Handling of Sales of Books, Pamphlets, Educational Lectures, etc., leaving the selection of Chairman and membership to the President, such to be approved by the Board of Directors after decision thereon. The Chairman outlined the work of this Committee and suggested that the first consideration would be a scope for the Committee. He advised that he had prepared such scope and was submitting such in the order following:

Supervise future editions of the WELDING HANDBOOK and study the demand and need for educational and text books on welding; arrange for preparation, publication, pricing, merchandising and distribution of all welding books, educational lectures and welding courses approved by the Board of Directors and sponsored by the SOCIETY; recommend the purchase of



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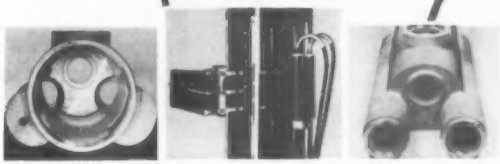

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"Our X-Ray tube housing is fabricated from eleven different parts that are assembled and welded. This assembly is then immersed in water and tested to withstand 50 lbs., air pressure to insure against leaks or porous welds. After the tube is joined, the inside of the housing is lined with lead to imprison the dangerous X-Rays.

An additional factor that makes this such a difficult metal-joining problem is the extremely wide temperature range to which the housing is subjected. The tube, ordinarily remaining at room temperature when not in use, rapidly attains a heat of 215°F. in operation, making the use of solder impractical.

Test after test of welding alloys in various price ranges had failed in one or another of the requirements. One of the chief causes of failure was the high heat at which conventional welding alloys are applied. This high heat either melted the delicate threading on the fittings or required extensive aftermachining and finishing before the crinkle finish could be applied to the completed piece.

Finally EutecRod 190, the new EUTECTIC Low Temperature WELDING ALLOY, was recommended and tested — and *met all requirements!* Expensive finishing was eliminated due to the unique thin-flowing characteristics of the alloys. Because of the low heat of application, the threads remained unharmed, rejects were eliminated, and production speed increased enormously. Tensile tests definitely proved that the strength of the joint was multiplied many times over—while the actual *cost per job decreased!*

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*—M-Laboratories, Connecticut**

*Full name and address on request.

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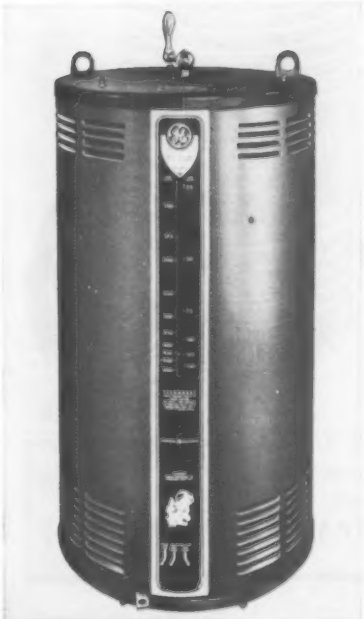

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GENERAL ELECTRIC

books published by other organizations for resale by AWS.

Action A: Upon motion, duly seconded, the Executive Committee approved of proposed scope for the Special Committee on Book Publications.

The Chairman then advised that there were a number of interests which must be served by such a Committee, such as methods for publishing and merchandising, the selection of proper authors, pricing and distribution, etc. It was advised that the Committee would consist of a Chairman who was well acquainted with the various publishing, merchandising, pricing and distribution requirements for such work, a metallurgical authority, a university authority, authorities from the gas-, resistance- and the arc-welding groups, a research authority, a TAC representative and an Educational Committee representative. He proposed that Irving B. Hexter, President of the Industrial Publishing Co., Cleveland, Ohio, be approached to serve as Chairman of this Committee.

Action B: Upon motion, duly seconded, the members of the Executive Committee approved the appointment of Irving B. Hexter as Chairman of this Committee on the basis of his acceptance of this Office.

By-Law Ratification

The Assistant Secretary reported that wording for Article III, Section 3, "Nonpayment of Dues," was submitted to the membership at large on Apr. 25, 1952, for letter ballot approval, as follows:

"Any member whose dues to the Society shall remain unpaid for a period of six months after they become due, shall be duly notified by the Secretary by letter *ballot* to the latest post office address as it appears on the records of the Society, stating that if such dues are not paid within a period of one month, he shall automatically cease to be a member of the Society."

This proposed wording was previously approved by the Constitution and By-Laws Committee and subsequently published in an issue of The Welding Journal. It was observed by several members of the Society, and rightfully so, that the wording "letter ballot" was incorrect and the proper terminology should be "letter." This matter was referred to the Society's attorney and he communicated with the Assistant Secretary suggesting that the Executive Committee ratify the adoption of the proposed amendment with the word "ballot" deleted and that announcement to this effect be made in a future Journal.

Action: Upon motion, duly seconded, the Executive Committee approved the attorney's suggestion that the word "ballot" be deleted and that announcement be published in a subsequent issue of The Welding Journal.

J. W. Owens Certificate

Chairman Jennings, in his capacity as Chairman of the Honorary Membership and Honorary Directorship Committee, presented proposed wording for the Honorary Membership Certificate for J. W. Owens.

Action: Upon motion, duly seconded, the Executive Committee approved wording for Honorary Membership Certificate, as modified, for J. W. Owens. Further that the Society's Secretary advise Mr. Owens of his appointment and arrange for presentation of the Certificate during the time of the Society's National Meeting in October in Philadelphia.

J. B. Tinnon Certificate

Chairman Jennings, in his capacity as Chairman of the Honorary Membership and Honorary Directorship Committee, presented proposed wording for the Honorary Membership Certificate for J. B. Tinnon.

Action: Upon motion, duly seconded, the Executive Committee approved wording for Honorary Membership Certificate, as submitted, for J. B. Tinnon. Further that the Society's Secretary advise Mr. Tinnon of his appointment and arrange for presentation of the Certificate during the time of the Society's National Meeting in October in Philadelphia.

AWS-ASTM Conference

The Chairman advised that on Wednesday, June 11, 1952, a Conference of officers and committee personnel of the ASTM and officers and committee personnel of the AWS joined in discussion regarding both Societies' contemplated activity in connection with specifications for weldments. He recalled that the Board of Directors had advised the calling of such a conference in the order of having been acquainted, through Mr. Bibber, that a Subcommittee of ASTM, A1 Committee, had indicated movement in a direction whereby

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it planned to compile and issue specifications dealing with weldments. Later it was reported to the Board of Directors that representatives from TAC had attended a meeting of the A1 Subcommittee in Philadelphia and at that meeting had advised the Chairman of the Subcommittee, N. L. Mochel, that in the opinion of AWS, specifications dealing with weldments were rightfully the work of AWS. The opposite viewpoint was held by Mr. Mochel in that the type of weldments to which he referred were those which by their nature should, in Mr. Mochel's opinion, be classed as "pieces of material." It was deemed advisable to await the next conference of the group for exploration of the submissions by Mr. Mochel and for TAC to proceed in the order previously planned.

TAC Recommendations

Item A consisted of Recommended Practices for Metallizing: "Part 1B—Application of Aluminum and Zinc for Protection of Iron and Steel" as a tentative standard prepared by the Subcommittee on Corrosion Applications of the AWS Committee on Metallizing, of Feb. 26, 1952, issue.

Action: Upon motion, duly seconded, the Executive Committee so approved. Item B consisted of "Recommended Practices for Inspecting and Repairing Elevated Steel Water Storage Tanks, Standpipes and Reservoirs" for publication as a joint standard of AWS and the American Water Works Association.

Action: Upon motion, duly seconded, the Executive Committee so approved.

Resignation of Assistant to Technical Secretary

C. D. Evans, Chairman of TAC, submitted the resignation of Ove Green, Assistant to the Technical Secretary. The Executive Committee accepted Mr. Green's resignation.

Engagement of Technical Department Assistant

The Chairman suggested that consideration be given immediately to replacing Mr. Green.

Qualifications for a suitable candidate were discussed and it was assumed (*a*) a man between the ages of 35 and 40 would not be attracted on the basis of the foregoing salary range, (*b*) a recent graduate from school, employed at a lower salary, may be found difficult to retain after he has acquired sufficient experience and (*c*) it was believed possible that an elderly man, retired from industry, could well meet the requirements for this position.

The TAC was advised to proceed with the employment of a Technical Department Assistant and that his employment must meet with the approval of the Society's Secretary. Further, that the salary range as recommended by Mr. Evans, Chairman of TAC, must meet with the approval of the Finance Committee, which Committee's action must be confirmed by the Executive Committee or the Board of Directors.

New AWS Section

A group located in Northern Alabama requested formal authority to operate as the Tri-Cities Section of the Society in that they have met with all the necessary steps for the establishment of a Section.

Action: Upon motion, duly seconded, the Executive Committee so approved.

New AWS Section

A group located in Des Moines, Iowa, requested formal authority to operate as the Iowa Section of the Society in that they have met with all the necessary steps for the establishment of a Section.

Action: Upon motion, duly seconded, the Executive Committee so approved.

Simplifying By-Laws

The Secretary observed that consideration has been given several times to the necessity of simplifying the By-Laws of AWS. The Chairman advised that the Secretary recently has received several letters from members, on the occasion of the recent balloting, protesting the waste attending the securing of membership approval every time a minor by-law requires changing. He advised that the Secretary's proposal consisted of by-laws simplified to an extent comparable to our Constitution and which would deal with the fundamental operations of the Society, which were of direct interest to the membership. The suggestion included the institution of changing many of the present by-laws to rules of procedure under which the Society's organization and staff would function and which rules of procedure would be issued by the Board of Directors and subject to change by Board action without necessarily being sent to the membership for vote thereon. It was generally agreed that this simplification was certainly in order. Discussion ensued regarding whether or not a new committee should be organized for this purpose or whether it should be referred to the Constitution and By-Laws Committee. The Chairman observed that any committee of the Society, including the Constitution and By-Laws Committee, had the right to appoint a subcommittee and that if it were referred to the Constitution and By-Laws Committee, should they not wish to do the work themselves, then they had the authority to appoint a subcommittee for this purpose.

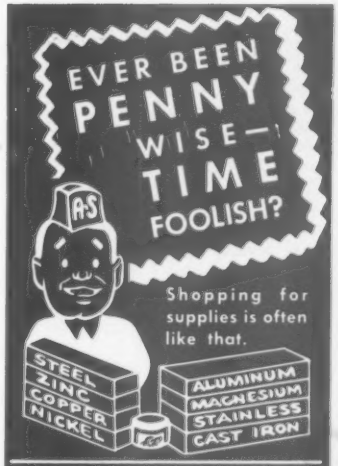
Action: Upon motion, duly seconded, the Executive Committee voted to refer this item to the Constitution and By-Laws Committee for review and recommendation to the Board of Directors of simplified by-laws and rules of procedure, the latter to be subject to change by Board of Directors' action only.

Expression of Appreciation

The Secretary advised that Mrs. I. H. Block has greatly assisted I. Morrison, correspondence- and activities-wise, during his year as Chairman of the National Membership Committee and he believes that an expression of appreciation should be forthcoming from the Society. The Executive Committee instructed the Secretary to thank Mrs. Block in behalf of the Board of Directors of the Society for her excellent and valued services.

Certificate of Award

The Secretary advised that the Board of



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White Plains, N. Y.

Directors had approved a plan for giving Past-President Certificates, and also approved plan for creating a certificate which would recognize effort by specific persons in the SOCIETY who had performed specific efforts of value to the SOCIETY. He observed that the cost of producing these certificates in small quantity was such that it was advisable, if possible, to combine these two requirements into one form serving both. Accordingly, he prepared a form which was submitted. Chairman Jennings offered further suggestions which, if incorporated, would provide a better vehicle for serving both purposes.

Action: Upon motion, duly seconded, the Executive Committee approved of certificate as rewritten.

Presentation of Certificates

The Secretary advised that he had planned to arrange a program during the Fall Meeting of the SOCIETY which might consist of a dinner for the National Officers, this group to also include all members of the Board of Directors and Chairmen of the various Standing Committees, including Past-Presidents of the SOCIETY. At this affair, a program would be arranged whereby the Past-Presidents present would be presented with their certificates. This program was generally approved by the Executive Committee.

Industry Organization Appointment

The Secretary advised that he had received an invitation from the Secretary and President of the International Acetylene Assn. to serve as a member of the IAA 1953 Annual Meeting Program Committee. He advised that this would not require a great deal of time but that, if possible, the invitation should be honored due to the close relationship of our two organizations.

Action: Upon motion, duly seconded, the Executive Committee approved of the Secretary's appointment to membership on the IAA 1953 Annual Meeting Program Committee.

Publicizing Annual Business Meeting

The Secretary advised that each year he checks with the Board of Directors or the Executive Committee to determine whether we wish to publicize the Annual Business Meeting so that added attendance can be secured. He stated that there have been two opposing opinions in the past, one wishing a nonpublicized meeting with small attendance, and the other wishing a large attendance meeting as a result of publicity. In general, the Executive Committee members were in favor of publicizing the meeting feeling that the SOCIETY should have as many of the membership present as is possible. Further, they felt that very likely it would be necessary this year, in view of the fact we may, as a result of the recommendations of the Special Committee on Membership Classification, find it advisable to introduce a resolution for change in the Constitution, such requiring an open meeting of the membership and open vote taken at the time of the Annual Business Meeting.

Chairman of Nominating Committee

Chairman Jennings, as President, advised that he was appointing H. W. Pierce, Past-President, as Chairman of the 1952–53 National Nominating Committee and that he was herewith submitting his appointment to the Executive Committee for approval.

Action: Upon motion, duly seconded, the Executive Committee so approved.

Appointment Tellers of Election

Chairman Jennings, as President, advised that he was appointing the Chairmen of the New York, New Jersey and Philadelphia Sections as Tellers of Election for canvassing the 1952–53 ballots, subject to the approval of the Executive Committee.

Action: Upon motion, duly seconded, the Executive Committee so approved.

1953 Adams Lecturer

The Secretary advised that the Adams Lecturer selection had been greatly delayed this year due to the absence of the Chairman of the Committee on Awards in Europe. It was Dr. Hoyt's intention on the basis of approval given by the Board of Directors, to have his Committee submit the name of a foreign lecturer for the consideration of the Board. The Secretary observed that the rules regarding the Adams Lecture indicate that the names of the nominees of the Awards Committee should be submitted to the Board of Directors and discussed by them prior to vote. He observed that this was only possible at the meeting of the Board which was not scheduled until late August. He suggested that he be allowed to send out a letter ballot to the Board members, if the nature of the Awards Committee's nominations permitted. The Executive Committee approved of the Secretary canvassing the Board of Directors by a mailed letter ballot, if such is necessary.

Nominating Committee Procedure

Mr. Fraser observed that the present by-laws in regard to membership on the National Nominating Committee are so written that they do not exclude the possibility of a nominating officer or member of the Board of Directors from serving on the National Nominating Committee concurrently. He observed that this has occurred two years successively and that some provision should be made for the retirement of the officer from one or the other office, preferably his office on the National Nominating Committee. The Secretary advised that such would be possible under our by-laws whereby a by-law vehicle exists allowing the District Executive Committee to replace a retiring member of the National Nominating Committee. Mr. Fraser suggested that this matter be brought to the attention of the Executive Committee or the Board of Directors at the next meeting.

Membership Status Report

Below is membership status report as submitted by the Assistant Secretary to the Executive Committee.

AMERICAN WELDING SOCIETY

MEMBERSHIP STATUS COMPARATIVE REPORT

MAY 31, 1951, VS. MAY 31, 1952

Active	Delinquent	Total registration
May 31, 1951		
A 112	A ..	A 112
B 3083	B 55	B 3138
C 3701	C 103	C 3804
D 227	D ..	D 227
E 9	E ..	E 9
F ..	F ..	F ..
7132	158	7290
May 31, 1952		
A 121	A ..	A 121
B 3428	B 70	B 3498
C 3870	C 112	C 3982
D 171	D ..	D 171
E 11	E ..	E 11
F 11	F ..	F 11
7612	182	7794

DELINQUENCY DROPS COMPARATIVE REPORT 1948, 1949, 1950, 1951, 1952

Month and year	Total registration before delinquent drops	Delinquent drops	Registered members dropped, %
Mar. 31, 1948	7933	735	9.3
Mar. 31, 1949	7921	799	10.1
Apr. 30, 1950	7694	617	8.0
Apr. 30, 1951	7687	421	5.5
Apr. 30, 1952	8013	346	4.3

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TENTATIVE PROGRAM

AMERICAN WELDING SOCIETY

33rd National Fall Meeting

week of October 19, 1952

THE BELLEVUE-STRATFORD, PHILADELPHIA, PA.

Welding and cutting demonstration will be featured at the National Metal Exposition held during the week at the Convention Halls

TECHNICAL SESSIONS

All Technical Sessions will positively start on time.

No Stenotype Reporter—Members desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to Headquarters, as those preparing written discussion will be given preference at the sessions. Members and guests giving extemporaneous discussion at meeting should forward a written discussion as soon as possible after the meeting.

MONDAY MORNING, OCTOBER 20th

10:00 A.M.—AWARD OF PRIZES

10:30 A.M.—ADAMS LECTURE

Chairman—CHARLES H. JENNINGS
President, American Welding Society

Co-Chairman—H. R. MORRISON
Chairman, Convention Committee

The Welding and Brazing of Titanium Alloys
by C. B. VOLDRICH, Battelle Memorial Institute

MONDAY AFTERNOON, OCTOBER 20th—2:00 P.M.

Three Simultaneous Sessions

1—FABRICATING PROCEDURES

Chairman—F. L. PLUMMER
Hammond Iron Works

Co-Chairman—H. C. CAMPBELL
Arcos Corp.

Fusion Welding Techniques for Jet Aircraft Components
by ARNOLD S. ROSE and MORTON A. BRAUN, I. T. E. Circuit Breaker Co.

Should Preheat Be Substituted for High-Temperature Stress Relief in the Codes?
by E. PAUL DeGARMO, University of California

Chromium - Recovery During Submerged Arc Welding
by JAMES G. KERR and DAVID A. ELMER, C. F. Braun & Co.

2—RESISTANCE WELDING

Chairman—T. EMBURY JONES
Precision Welder & Machine Co.

Co-Chairman—J. J. MacKINNEY
Budd Co.

Corrosion of Structural Spot Welds
by B. KARNISKY, E. P. GRUCA and E. KINELSKI, Pullman-Standard Car Mfg. Co.

Maintenance of Resistance Welders in High-Speed Assembly Lines
by JAMES F. SALATIN and O. D. ETCHISON, Delco-Remy Division, General Motors

3—HARD FACING AND FLAME HARDENING

Chairman—E. H. ROPER
Air Reduction Sales Co.

Co-Chairman—R. A. GUENZEL
Southern Oxygen Co.

Hard Facing Alloys of the Chromium Carbide Type
by HOWARD S. AVERY and HENRY J. CHAPIN, American Brake Shoe Co.

Selection and Evaluation of Methods of Hard Facing
by JACK J. BARRY, Air Reduction Sales Co.

Flame Hardening of Large-Diameter Thin-Wall Cylindrical Shells
by G. S. WING and G. A. WEBER, M. W. Kellogg Co.

MONDAY EVENING, OCTOBER 20th—6:00 P.M.

President's Reception

TUESDAY MORNING, OCTOBER 21st—9:30 A.M.

Three Simultaneous Sessions

4—RESISTANCE WELDING

Chairman—JACK OGDEN
Fisher Body Div., General Motors

Co-Chairman—K. W. OSTROM
K. W. Ostrom & Co.

Calculation of Spot-Weld Properties
by JULIUS HEUSCHKEL, Westinghouse Electric Corp.

Temperature Distribution During Flash Welding of Steel—Part II
by ERNEST F. NIPPES, WARREN F. SAVAGE, JOHN J. McCARTHY and SHERIDAN S. SMITH, Rensselaer Polytechnic Institute

Spot Welding of Titanium Alloy Sheet
by M. L. BEGEMAN, EDWIN H. BLOCK, Jr., and FRANK W. McBEE, Jr., The Univerity of Texas

Spot Welding Magnesium with Three-Phase Low-Frequency Equipment
by DEAN L. KNIGHT and PAUL THORNE, National Electric Welding Machines Co., and PAUL KLAIN, Dow Chemical Co.

5—WELDABILITY

Chairman—R. E. SOMERS
Bethlehem Steel Co.

Co-Chairman—A. B. GORDON
Linde Air Products Co.

Further Studies of the Crack Sensitivity of Aircraft Steels
by A. W. STEINBERGER and J. STOOP, Curtiss Wright Corp., Propeller Div.

Effect of Geometry on Stresses in Circular Patch Specimen
by ALAN V. LEVY and HARRY E. KENNEDY, University of California

Evaluation of the Circular-Patch Weld Test
by JOHN E. HOCKETT and L. O. SEABORN, University of California

Relationship of Welding Technique to Penetration and Dilution
by CLARENCE E. JACKSON and ARTHUR E. SHRUBSALL, Union Carbide and Carbon Research Laboratories, Inc.

6—STRUCTURAL

Chairman—LAMOTTE GROVER
Air Reduction Sales Co.

Co-Chairman—I. E. BOBERG
Chicago Bridge & Iron Co.

The Behavior of Welded Portal Frames
by E. R. JOHNSTON, LYNN S. BEEDLE, Fritz Engineering Laboratory, Lehigh University, and J. M. RUZEK, C. F. Braun & Co.

Residual Stress and the Compressive Strength of Steel
by LYNN S. BEEDLE, A. W. HUBER, Fritz Engineering Laboratory, Lehigh University, and BRUCE G. JOHNSTON, University of Michigan

How to Save Cost by Designing for Structural Welding
by ALFRED E. PEARSON, The Ingalls Iron Works Co.

Distortion Control in Structural Fabrication
by GORDON CAPE and LLEWELLYN JEHU, Dominion Bridge Co., Ltd.

TUESDAY AFTERNOON, OCTOBER 21st—2:00 P.M.

Three Simultaneous Sessions

7—WELDABILITY

Chairman—E. M. MacCUTCHEON, Jr.
Bureau of Ships, Navy Department

Co-Chairman—L. J. LARSON
Allis-Chalmers Mfg. Co.

The Effect of Strain Rate on Twinning and Brittle Fracture in Low-Carbon Steel
by D. ROSENTHAL and C. C. WOOLSEY, Jr., University of California

Interpretation of Test Data Regarding Brittle Strength and Transition Temperature of Structural Steel
by N. M. NEWMARK and W. C. HOELTJE, University of Illinois

Factors Affecting the Resistance of Pressure Vessel Steels to Repeated Overloading
by ROBERT D. STOUT, JOHN H. GROSS and SCHILLINGS TSANG, Lehigh University

8—RESISTANCE WELDING

Chairman—J. H. COOPER
The Taylor-Winfield Corporation

Co-Chairman—W. G. FETTER
P. R. Mallory & Co.

Quality Control of Resistance Welding by Statistical Methods
by J. F. RADFORD and R. K. WALDVOGEL, Crosley Division, Avco Mfg. Corp.

Contact Resistance as Affected by Subdividing the Contact Area
by WILLIAM B. KOUWENHOVEN and CLARENCE W. LITTLE, Jr., The Johns Hopkins University

New Multispot Control Provides Increased Welding Production with Limited Power Supply
by CLAUDE R. WHITNEY, Jr., Square D Co.

9—BRAZING AND BRONZE WELDING

Chairman—J. J. VREELAND
Chase Brass & Copper Co.

Co-Chairman—L. H. HAWTHORNE
Revere Copper & Brass, Inc.

New Aspects in Surface Alloying in Brazing and Related Techniques
by DR. ROBERT HUMPHREY and RENE D. WASSERMAN, Eutectic Welding Alloys Corp.

Strength Joints to Steel with Aluminum Bronze Filler Metals
by WILLIS G. GROTH, Ampco Metal, Inc.

TUESDAY AFTERNOON, OCTOBER 21st—4:30 P.M.

EDUCATIONAL LECTURE SERIES

Chairman—GILBERT E. DOAN

The Inert-Gas Metal-Arc-Welding Process
by WALTER H. WOODING, Philadelphia Naval Shipyard

TUESDAY EVENING, OCTOBER 21st—6:30 P.M.

Section Officers Dinner and Meeting

WEDNESDAY MORNING, OCTOBER 22nd—9:30 A.M.

PLANT VISIT

Three Simultaneous Sessions

10—NONFERROUS

Chairman—O. B. J. FRASER
International Nickel Co.

Co-Chairman—J. R. HUNTER
Westinghouse Electric Corp.

The Semiautomatic Inert-Gas Metal-Arc Welding of Aluminum Alloys
by CHARLES T. GAYLEY, JOSEPH R. GIRINI and WALTER H. WOODING, Industrial Test Laboratory, Philadelphia Naval Shipyard

Welding 90-10 Cupro-Nickel by the Inert-Gas-Shielded Arc Processes
by L. H. HAWTHORNE, Revere Copper and Brass, Inc.

Weld Cracking of Aluminum Alloys
by JAMES D. DOWD, Aluminum Company of America

11—WELDABILITY

Chairman—L. C. BIBBER
United States Steel Co.

Co-Chairman—R. H. LAMBERT
Captain, USN

Relation of Preheating to Low-Temperature Cooling Rate Embrittlement and Microcracking
by A. E. FLANIGAN and T. MICLEU, University of California

Initiation and Propagation of Brittle Fracture in Structural Steels
by PETER P. PUZAK, EARL W. ESCHBACHER and WILLIAM S. PELLINI, Naval Research Laboratory

The Continuous Cooling Transformation of Weld Heat-Affected Zones
by W. R. APBLETT, Jr., L. K. POOLE and W. S. PELLINI, Naval Research Laboratory

The Determination of Optimum Conditions for the Automatic Welding of Hardenable Steels
by C. R. McKINSEY and J. F. COLLINS, Union Carbide & Carbon Research Laboratories, Inc.

12—TITANIUM ALLOYS

Chairman—COLONEL B. S. MESICK
Ordnance Corps, Watertown Arsenal

Co-Chairman—CARL E. HARTBOWER, Watertown Arsenal

Practical Aspects of Arc Welding Titanium Alloys
by J. J. CHYLE and IVAN KUTUCHIEF
A. O. Smith Corp.

The Effects of Fe, Mn, Cr and Mo on Welds in Titanium
by G. E. FAULKNER, G. B. GRABLE and C. B. VOLDRICH, Battelle Memorial Institute

An Investigation of the Thermal Cycles Adjacent to Arc Welds in ½ Inch Titanium Plate
by E. F. NIPPES, J. M. GERKEN and B. W. SCHAAF, Rensselaer Polyechnic Institute

Contaminants in Welding Titanium
by R. W. HUBER and THOMAS R. GRAHAM, Bureau of Mines

WEDNESDAY AFTERNOON, OCTOBER 22nd—2:00 P.M.

Three Simultaneous Sessions

13—WELDABILITY

Chairman—R. D. THOMAS, Jr.
Arcos Corp.

Co-Chairman—C. B. JENNI
General Steel Castings Corp.

Embrittlement of High-Strength Ferritic Welds
by PETER P. PUZAK and WILLIAM S. PELLINI, Naval Research Laboratory

Temper Brittleness in Low-Alloy Metal
by RICHARD P. WENTWORTH and HALLOCK C. CAMPBELL, Arcos Corp.

The Effects of Electrodes and Welding Conditions on the Ductility of Arc-Welded Mild Steels
by ERNEST F. NIPPES and ALEXANDER LESNEWICH, Rensselaer Polytechnic Institute

14—NONFERROUS

Chairman—G. O. HOGLUND
Aluminum Company of America

Co-Chairman—J. S. DOUGLASS
Linde Air Products Co.

The Strength and Ductility of Welds in Aluminum Alloy Plate
by F. M. HOWELL and F. G. NELSON, Jr., Aluminum Research Laboratories

Factors Which Determine the Performance of Aluminum Alloy Weldments
by W. R. APBLETT, JR., C. R. FELMLEY and W. S. PELLINI, Naval Research Laboratory

Welding and Forming of Titanium
by FRANCIS H. STEVENSON, Aerojet Engineering Corp.

15—Maintenance and Gas Cutting

Chairman—H. V. INSKEEP
Linde Air Products Co.

Co-Chairman—A. M. GARCIA
Morris, Wheeler & Co., Inc.

Wear and Operation Problems in Maintenance
by FRANK J. GAYDOS, United States Steel Co., Gary Works

Effect of Oxygen Cutting on Alloy Steel
by F. C. SAACKE, Air Reduction Co., Inc.

WEDNESDAY AFTERNOON, OCTOBER 22nd—4:30 P.M.

EDUCATIONAL LECTURE SERIES

Chairman—GILBERT E. DOAN

The Inert-Gas Metal-Arc Welding Process
by WALTER H. WOODING, Philadelphia Naval Shipyard

WEDNESDAY EVENING, OCTOBER 22nd

6:30 P.M.

National Officers Dinner and Meeting

8:00 P.M.

WRC University Research Conference

THURSDAY MORNING, OCTOBER 23rd—9-30 A.M.

Three Simultaneous Sessions

16—INERT ARC WELDING

Chairman—C. I. MacGUFFIE
General Electric Co.

Co-Chairman—K. L. WALKER
Foster Wheeler Corp.

A Comparison of Shielding Mixtures for Gas-Shielded Arc Welding
by JOHN W. CUNNINGHAM, Air Reduction Co., Inc.

Production Welding of Mild and Low-Alloy Steels by Gas-Shielded Arc Welding
by JOHN H. BERRYMAN, Air Reduction Co., Inc.

Porosity in Mild Steel Weld Metal
by DONALD WARREN, E. I. du Pont de Nemours & Co., Inc., and R. D. STOUT, Lehigh University

17—BRAZING

Chairman—A. N. KUGLER
Air Reduction Co., Inc.

Co-Chairman—A. M. SETAPEN
Handy & Harman

Advanced Information for the Brazing Operator
by E. F. DAVIS, Westinghouse Electric Corp.

Joint Design for Brazing
by W. J. VAN NATTEN, General Electric Co.

Technical Aspects of Soldering Practices
by R. M. MacINTOSH, Tin Research Institute, Inc.

Production Brazing
by J. R. WIRT, Delco-Remy Division, General Motors Corp.

18—MARINE CONSTRUCTION

Chairman—DAVID P. BROWN
American Bureau of Shipping

Co-Chairman—A. A. HOLZBAUR
Sun Shipbuilding & Dry Dock Co.

New Rules for Welding Low-Alloy Ferritic Pipe Material
by COMMANDER CHARLES F. PERRY, USCG

Evaluation of Brittle Failure Research
by PAUL FFIELD and ED SWEENEY, Bethlehem Steel Co.

An Investigation on Peening
by P. L. CALAMARI, F. J. CRUM and G. W. PLACE, American Bureau of Shipping

THURSDAY AFTERNOON, OCTOBER 23rd

2:00 P.M.

Business Meeting

3:00 P.M.

Board of Directors Meeting

THURSDAY EVENING, OCTOBER 23rd

7:00 P.M.

Annual Dinner

FRIDAY MORNING, OCTOBER 24th—9:30 A.M.

Three Simultaneous Sessions

19—PIPE

Chairman—E. R. SEABLOOM
Crane Co.

Co-Chairman—A. J. ERLACHER
United Engineers & Constructors

Pipe Welding in the Petroleum Refining Industry
by ALBERT W. ZEUTHEN, Socony Vacuum Oil Co.

The Arc Welding of Low Chromium-Molybdenum Steel Pipe
by J. BLAND, L. J. PRIVOZNIK and F. J. WINSOR, Standard Oil Company of Indiana

Effect of Stresses and Stress Relief on the Bursting Strength of Circumferentially Welded Pipe
by L. J. PRIVOZNIK and F. J. WINSOR, Standard Oil Company of Indiana

20—INERT ARC

Chairman—C. D. EVANS
International Harvester Co.

Co-Chairman—N. E. WHEELER
GMC Truck and Coach Division

Inert-Gas Shielding of the Metallic Arc
by WILLIAM L. GREEN and ROBERT J. KRIEGER, The Ohio State University

Gas Flow Requirements for Inert-Gas Arc Shielding
by GLENN J. GIBSON, Air Reduction Co., Inc.

Shielded Arc Welding of Jet Engine Components
by K. H. KOOPMAN, Linde Air Products Co.

21—MARINE CONSTRUCTION

Chairman—H. W. PIERCE
New York Shipbuilding Corp.

Co-Chairman—J. LYELL WILSON
Consultant Naval Architect

Prevention of Marine Corrosion by Metallizing Systems
by HOWARD VANDERPOOL, Metallizing Engineering Co.

Observations on Experience with Welded Ships
by DAVID P. BROWN, American Bureau of Shipping

Failures and Defects Encountered in Welded Ship Construction
by RALPH D. BRADWAY, New York Shipbuilding Corp.

Remember the trade marks "tt" and "TUBE-TURN" are applicable only to products of TUBE TURNS, INC.

Streamline your purchase of welding fittings

Scrappy says, "Aid defense—more scrap today... more steel tomorrow."

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JUST AS THE USE of welding fittings streamlines a piping system so does the standardizing on TUBE-TURN Welding Fittings streamline your purchasing operations.

The TUBE-TURN Welding Reducer, both in the concentric type shown here and the eccentric type, is available in a complete range of sizes, wall thicknesses and types of materials. This is another example of how the complete TUBE TURNS' line is designed to meet all your requirements. It covers over 4000 different items. Thus you can simplify ordering and deliveries for any piping job by obtaining all your welding fittings and flanges from one reliable source . . . your TUBE TURNS' Distributor. You'll find one in every principal city.

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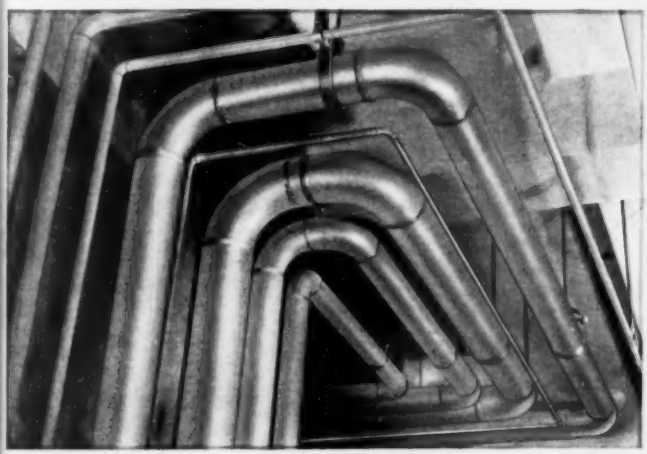
30 Stories of New Building Ideas
...includes maintenance-free welded piping

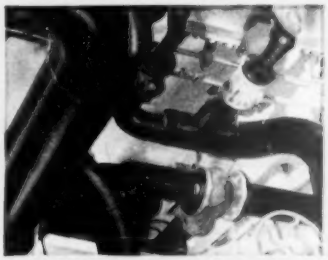
ALUMINUM COMPANY OF AMERICA'S new 30-story office building in Pittsburgh is a pacesetter for construction ideas. Exterior walls are made of sheet aluminum. Windows pivot on vertical axes to simplify cleaning. Radiant heating and cooling panels in ceilings increase rentable floor space.

In keeping with this progressive design, a welded piping system, using TUBE-TURN Welding Fittings and Flanges, was specified. Thus piping, both aluminum and steel, will be leak-proof and maintenance-free. The variety of welding-fitting requirements posed no problem, since TUBE TURNS, INC. offers the world's broadest line of welding fittings and flanges—available in a wide range of types, sizes, and more than 40 different metals and alloys.

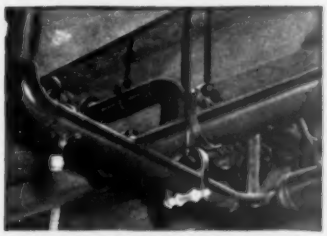
Alcoa's new office building. Architects: Harrison & Abramovitz. Assoc. Architects: Mitchell & Ritchey and Altenhof & Bown. Heating, Ventilating & Air Conditioning Sub-Contractors: Dravo Corp.; Plumbing Contractors: Sauer, Inc.



Corrosion-resistant aluminum lines for drinking, and hot and cold water supply saved critical copper. Note how welded lines, from 1" up, are fitted closely together, make for a neat installation. These lines will be insulated.



TUBE-TURN Welding Elbows, Tees, and Reducers used in steel piping for steam and hot water lines in basement. True circularity and uniform wall thickness of TUBE-TURN Welding Fittings expedited installation by insuring accurate fit.



Eight-inch steam line with 2" and 3" branches in fan room on roof. Use of welded system, with TUBE-TURN Welding Fittings, simplified piping design, gives streamlined appearance, eliminates maintenance problems.

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When you gas weld aluminum . . .

Your local Alcoa Distributor is a good man to know when you must teach inexperienced workers how to weld and braze aluminum.

Through him you are offered the world's most complete technical library on joining aluminum—how-to-do-it movies, plus copies of a 186-page book covering all welding processes.

You'll find your local Alcoa Distributor listed under "Aluminum" in your classified phone book. Or write:

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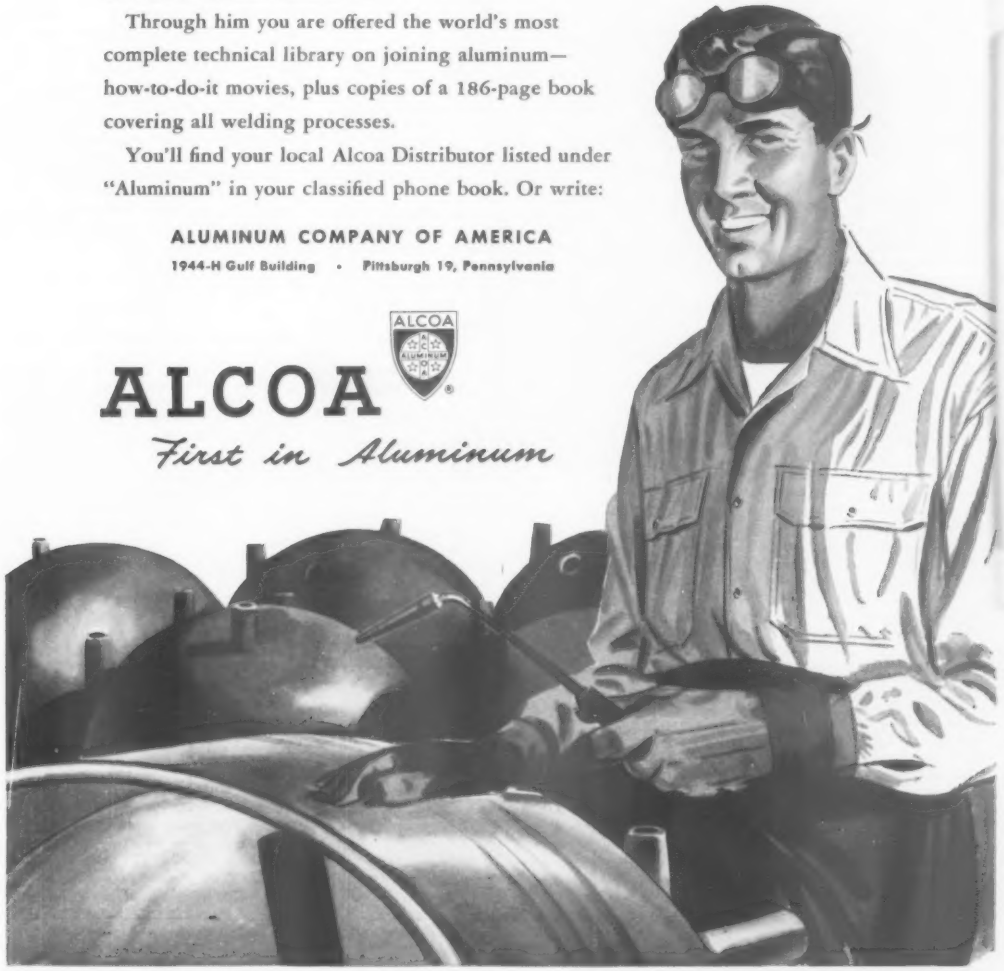


NEWS OF THE INDUSTRY

ASTM Officers for 1952–53

The election of new officers of the American Society for Testing Materials for the ensuing year was announced at the 50th Anniversary Meeting held in New York City, June 23rd to 27th. The new President is Dr. Harold Lee Maxwell, Supervisor of Mechanical Engineering Consultants, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del. Norman L. Mochel, Manager, Metallurgical Engineering, Westinghouse Electric Corp., Philadelphia, is the new Vice-President. The following men have been elected to the Board of Directors for a term of three years: George R. Gohn, Supervisor, Creep and Fatigue Laboratories, Bell Telephone Laboratories, New York City; William H. Lutz, Technical Director, Pratt & Lambert, Inc., Buffalo, N. Y.; Howard K. Nason, Research Director, Organic Chemicals Division, Monsanto Chemical Co., St. Louis, Adolph O. Schaefer, Vice-President in Charge of Engineering and Manufacturing, the Midvale Co., Nicetown, Philadelphia; and Myron A. Swayze, Director of Research, Lone Star Cement Corp., New York City. Dr. Maxwell and Mr. Mochel are members of the AMERICAN WELDING SOCIETY.

Swiss Acetylene Society

The annual report of the Swiss Acetylene Society for 1951 states that it conducted 28 welding courses attended by 438 students. Prof. C. G. Keel presented two courses of lectures and demonstrations on welding in the Federal Polytechnic. The Society published its monthly journal (234 pages) carried on its advisory activities, and prepared a new movie on capillary brazing. The inspection service of the Society inspected over 2000 items of gas-welding equipment. The president of the Society for 1951–52 is Dr. P. Schläpfer. The head of the Technical Committee is Dr. H. Rufener. The Society now has 1269 members.

Business has been very good in Switzerland during 1951. About 100,000 laborers from foreign countries had to be brought to Switzerland to meet the demand. Steel sheet and wire, and copper alloys were in very short supply. Sales of calcium carbide were high, about 2000 tons of Swiss carbide being exported. Nickel alloys were difficult to process. Domestic manufacturers of oxygen and acetylene and related equipment had a good year, but electrode manufacturers have lost the Swiss market partly to foreign suppliers. There has been a considerable increase in sales of resistance welders equipped with electronic controls.

Webb Institute of Naval Architecture

The 57th Annual Commencement of Webb Institute of Naval Architecture, Glen Cove, Long Island, N. Y., was held June 30th. Walter L. Green, Chairman of the Board and President of the American Bureau of Shipping and a Trustee of Webb, and AWS member, addressed the graduates in the presence of a number of notables, among whom were Rear Admiral Gordon McLintock, Superintendent of the United States Merchant Marine Academy at Kings Point, L. I., and Rear Admiral Logan McKee, Supervisor of Shipbuilding, New York, N. Y.

Diplomas were handed to the graduates by Cletus Keating, President of Webb, who also delivered the Address of Welcome. The commencement exercises were presided over by Rear Admiral Frederick E. Haeberle, USN (ret.), Administrator of the Institute, and formerly Assistant Chief, Bureau of Ships, Department of the Navy.

Prizes for honor students were awarded by J. Lyell Wilson, member of the Board of Trustees and Committee on Education and AWS member. There were nine graduates. Student speaker at the commencement exercises was David W. Lerch III. This year the demand from the maritime industries for the graduates was far in excess of the number graduating.

Webb is the only institution of its type in the United States exclusively teaching naval architecture and marine engineering, and conferring the degrees of Bachelor and Master of Science. It is a wholly endowed school, founded in 1889 by William H. Webb, a prominent clipper shipbuilder of that era. The Institute moved in 1947 from its original location in the Bronx, N. Y., to the present site acquired from the Herbert L. Pratt estate, where it now has 28 acres with modern buildings and school facilities, together with a new ship-model testing basin, and complete electrical, mechanical, chemical, physical and metallurgical laboratories.

Airco Holds Open House at Acton, Mass.

Air Reduction recently held open house at its plant in Acton, Mass. Local civic and business leaders attended at Airco's invitation to inspect the recently completed expansion of its facilities.

Airco came to Acton in 1949 with a small plant for the production of acetylene. The expansion plan which began about a year ago included enlargement of the acetylene-producing equipment, addition of a hydrogen-producing unit and installation of a liquid oxygen substation. This plant now brings a readily available supply of these gases to the community and the surrounding area.

In welcoming the guests, A. S. Blodget, Jr., manager of Airco's Boston district said, "it has always been our aim to be a good industrial citizen of the communities in which we operate. We want to know the community better and we want the community to know us."

Following a guided tour of the plant, the visitors witnessed a series of demonstrations to show some of the many uses of Airco's products. Liquid air came into play to start the show and was followed by oxy-acetylene cutting, and welding with the Aircomatic® process that has been hailed as the greatest advance in the welding industry in the past decade. Also there were exhibits of products made by other Air Reduction Divisions. This exhibit gave the guests an indication of the diversification of the company. In addition to gases and welding equipment, the company produces products ranging from medical equipment to "Dry-Ice."

Following the open house a reception was held at the Mail Coach Grill, Route 2, East Acton, Mass.

Research on Standardization

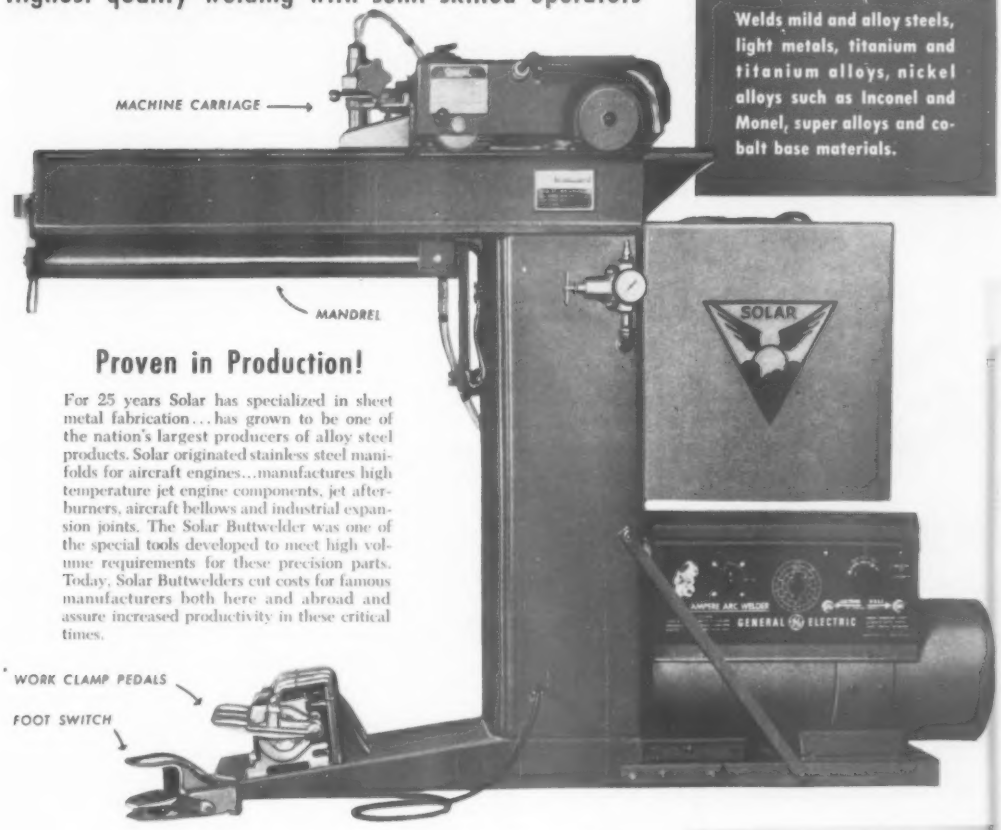
A Fellowship for conducting systematic studies of standardization and its applications in science, engineering, production and marketing has been announced by Dr. Edward R. Weidlein, President, Mellon Institute, Pittsburgh, Pa. This Fellowship will be sustained at the Institute by a grant from the Sarah Mellon Scaife Foundation of Pittsburgh, and its projects will be organized and supervised by Dr. Dickson Reck, Advisory Fellow. Dr. Reck will work in cooperation with research specialists of the Institute and with national authorities and societies.

Dr. Reck is lecturer in business administration at the University of California. He holds a B.S. degree in industrial management from the University of Illinois, a Ph.D. degree in economics from Columbia University, and has taught economics and marketing at the University of Pennsylvania. He has had wide experience in the field of industrial administration and standardization. For ten years he was with the Square D Co., manufacturer of electrical equipment, in Detroit, Mich. In the early years of World War II Dr. Reck was head of the Standards Division of OPA, and from 1944 to 1947 he was on detail from the Department of State to the Government of the Republic of China, by which he was appointed adviser on industrial organization and standardization. Later, from 1947 to 1950, the Department of Defense sent him to Japan to give attention to problems of technology and

Solar Buttwelder Speeds Production, Cuts Costs

Highest quality welding with semi-skilled operators

Welds mild and alloy steels, light metals, titanium and titanium alloys, nickel alloys such as Inconel and Monel, super alloys and cobalt base materials.



Proven in Production!

For 25 years Solar has specialized in sheet metal fabrication... has grown to be one of the nation's largest producers of alloy steel products. Solar originated stainless steel manifolds for aircraft engines... manufactures high temperature jet engine components, jet afterburners, aircraft bellows and industrial expansion joints. The Solar Buttwelder was one of the special tools developed to meet high volume requirements for these precision parts. Today, Solar Buttwelders cut costs for famous manufacturers both here and abroad and assure increased productivity in these critical times.

Automatic production of flawless welds

Joins flat sheets perfectly . . . fabricates smooth cylinders

SOLAR BUTTWELDERS *provide a fast production means for automatic seam welding of a wide variety of metals. Ideal for fabricating cylindrical tubes and for joining strips or sheets with smooth, ductile buttwelds. The inert gas shielded arc and the Solar-developed* expanding clamp produce uniform weldments which meet the most rigid specifications.*

Solar Buttwelders efficiently handle metals from .005 to .187 in. thick. Most applications require no filler wire, but it can be added automatically when desired. Easy to load and clamp. Highly skilled operators are not essential.

Solar Buttwelders are available in two standard sizes: one welds seams up to 30 in. long and a larger model, seams up to 66 in. Speed range of 4 to 30 ipm may be increased by simple gear change to provide 10 to 120 ipm range.

Electrical components are best quality units fabricated by leading equipment manufacturers. Machines are shipped complete; customer connects electricity, inert gas (helium or argon), air and water only.

TITANIUM ring fabricated with the aid of a Solar Buttwelder. Weld easily exceeds ductility requirements set by standard bend tests and showed no cracking after distortion.

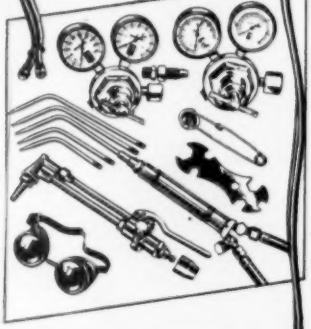
For complete information write Solar Aircraft Company, Dept. 81, San Diego 12, California

SOLAR AIRCRAFT COMPANY 1927 1952

Designers, Developers and Manufacturers of Precision High-Temperature Products

SAN DIEGO DES MOINES

FOR
OXY-ACETYLENE
WELDING and
CUTTING



DOCKSON'S
№ 145 OUTFIT

fitted for a complete range of all-purpose welding and cutting operations as heavy as 5" steel.

No. 145 OUTFIT includes:

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1—Ea. Nos. 2, 4, 6, 8 and 10 "E" Style Elbow Tips.
1—C-4 Hi-Speed Cutting Attachment.
1—C-2 Cutting Tip.
1—No. 134-BE Oxygen Regulator, 200 lb. and 3000 lb. gauges.
1—No. 134-AD Acetylene Regulator, 60 lb. and 500 lb. gauges.
1—Commercial to P. O. L. Adapter.
1—12½ ft. length ¼" Siamese Hose.
4—Hose Connections.
1—Outfit Wrench.
1—Round File Gas Lighter.
1—Pr. Series 66-19-6 Welding Goggles.

THERE IS A DOCKSON DISTRIBUTOR NEAR YOU — Let us send you his name and our catalog of Welding and Cutting Equipment, a complete line "BUILT FOR BETTER SERVICE".

Dockson CORPORATION
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standardization. More recently he was engaged as an adviser to the American Standards Association. He is the author of a number of publications in the fields of marketing and industrial management.

Soldering of Aluminum Showcase Rails

How to make beautiful showcases quickly and at low cost is being demonstrated at Hess Brothers Department Store in Allentown, Pa. The techniques involves the soldering of extruded aluminum rails with color matching aluminum solder and flux.

With these showcases, it is absolutely necessary to have a matching color and very tight joints so that appearance is everything to be desired. In fabricating, therefore, the rail is first cut to length, joints are mitered and carefully fitted. The parts are then placed in a jig to hold the parts in position for joining. The extruded aluminum has a hard baked skin surface, which is scraped from the ends of the rail. The ends are then tinned with aluminum solder.

A slightly acetylene flame is applied keeping the heat input at about 400° F, to the ends of the rail to be joined, and when soldering filler metal shows signs of melting, it is applied to the rail ends, flowing through the joint as far as possible, from the reverse side of the rail. A paddle, made of $^1/_8$-in. steel rod, is used to puddle the metal at the joint. More metal is added to give the joint a good cross section for strength, and then the joint is allowed to cool for 15 min. After that, the rails joined can be moved to complete other joints in succession.

All-State No. 39 Solder and Flux are used in the fabrication of these specific showcases.

Midwest Piping Builds Large Addition to Welding Fittings Plant

Midwest Piping and Supply Co., Inc., St. Louis, Mo., has just completed a large addition to the welding fittings manufacturing plant, according to an announcement by A. G. Stoughton, President.

The new addition adds 48,000 sq ft of floor space and more than doubles the

pressing and welding capacity. With equipment, the structure represents an investment of one-half million dollars.

Equipment is now complete except for a new press capable of producing welding elbows up to 36 in. pipe diameter. It is hoped to have this new press in service before the year closes.

Stud Welding Used in Construction of New Boston Pier

Contractors responsible for erection of the Port of Boston Authority's new Mystic Pier No. 1 have made use of stud welding to solve two difficult problems, one presented by the building design and the other by atmospheric conditions in a 240,000-sq ft transit shed surrounded on three sides by sea water.

Approximately 560 squares of corrugated asbestos siding (Careystone), which completely encloses the building, were installed with $^1/_4$ x $1^1/_2$-in. stainless steel studs which were end-welded with the Nelson stud welding gun (see Fig. 1).

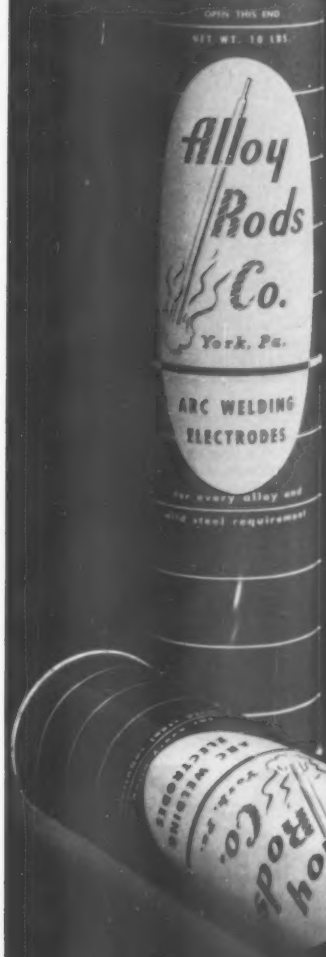
Use of these fasteners, with solid zinc alloy collarnuts, and of cadmium plated studs for installation of corrugated asbestos interior fire curtains, was specified in place of stainless steel clips and bolts for a neater-appearing, more positive connection, and to make for easier installation in a difficult location. Interior appearance has been greatly enhanced and maintenance simplified, as other fasteners reportedly would have marred the white enamel finish coating used to protect the steel girts and purlins on the inside.

The fact that more than 32,000 lineal feet of sprinkler lines installed in this transit shed had to be placed above the bottom chord of the welded roof trusses, which support a flat concrete roof deck, created another difficult problem, because there was no place to fasten clamps of the type commonly used for suspension of sprinkler pipe.

HIDDEN STRENGTH

in trained hands

. . . there's more than meets the eye in Alloy Rods arc welding electrodes



NO WELDING ROD is better than the skill of the welder using it . . . but any skilled welder can get consistent *quality* welds, faster and cheaper, using *Alloy Rods'* seven complete lines.

Principal reasons: *Alloy Rods'* continuous *quality control*—continually producing identical characteristics in each grade of electrode from every production run . . . continuous on-the-line testing and inspection . . . the continuous efficiency and exclusive production techniques of the world's most modern electrode manufacturing plant, *producing arc welding electrodes only.*

Although our Distributors may temporarily be out of stock on certain types, we urge you to keep in touch with them on your requirements. After all, *quality* is always worth waiting for.

NAMES TO REMEMBER IN ARC WELDING

ARCALOY for stainless steel
ARMORARC for armor welding
BRONZE-ARC for bronze and cast iron
NICKEL-ARC for cast iron
TOOL-ARC for tool steel
WEAR-ARC for hard-facing
WELD-ARC for low hydrogen electrodes

Contact your Alloy Rods Distributor or write for specific product Bulletins.

AR-4

ALLOY RODS COMPANY

No Finer Electrodes Made . . . Anywhere

YORK, PENNSYLVANIA

Ultimately, more than 4000 $^1/_2$- x 2-in. female studs were stud welded on the underside of the flanges at the top of the trusses and $^3/_8$-in. rods of the proper length were used to extend the supports to the level at which the sprinkler lines have been suspended.

SESA Meeting

Society for Experimental Stress Analysis Annual Meeting, December 3, 4, 5, 1952, Hotel McAlpin, New York, N. Y.

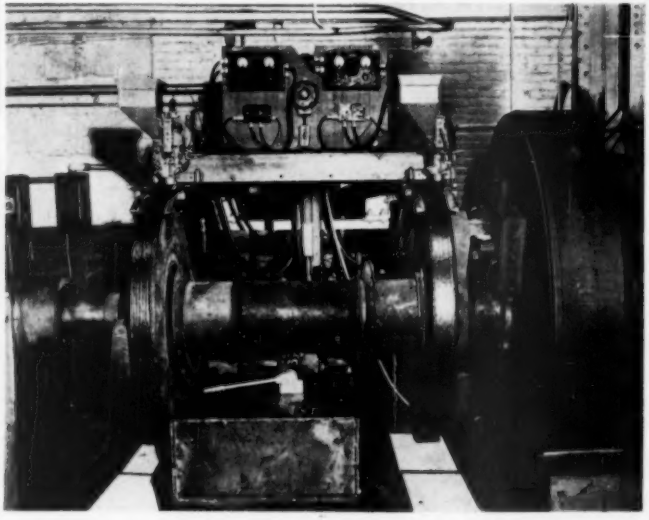
Exhibition on December 3rd and 4th only.

Automatic Welding Build-Up of Wheel Centers

Several railroad shops are helping to keep steam locomotives in active service by building up badly worn wheel centers with submerged arc welding. This high-speed welding method not only keeps the "old iron horses" working, it also makes possible large economies because welding time is greatly decreased—two hours to deposit $^1/_4$ in. thick build-up on two 50-in. diameter wheels.

As shown in the illustration, the wheels on the axle are mounted in a wheel lathe. The treads are under two Unionmelt UE type heads mounted on a special bracket fastened to a tool post. Continuous lateral movement of the heads so as to carry the metal bead across the areas being built up is accomplished by the feed screw. It is important to note that the setup includes four spring-loaded copper-retaining shoes about 13 in. long formed to the radius of the wheels. These shoes are on each side of the wheels to retain the granular welding composition. As welding proceeds, the excess composition falls off the wheels and is caught in the mesh-covered troughs under each wheel.

Usual build-up is about $^1/_4$ in. thick in overlapping beads $^5/_{16}$ in. wide. Approximately 20 beads cover a 5-in. wide wheel center.



(Courtesy of Union Carbide and Carbon Corp.)

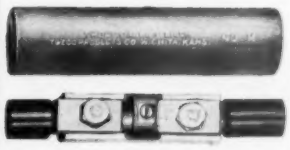
Cast steel wheel centers for locomotives are rebuilt by submerged-arc welding—two at a time

Steam on high

Steam on High

Rising 38 ft above the floor, this maze of steel tubes is part of the boiler furnace section of Ohio's largest and newest spreader stoker fired steam generating unit. Water circulating through the tubes will be turned into steam to supply power for the B. F. Goodrich Co. in Akron. When the heat is on, temperature where the welder is burning the finishing touches will range between 2000 and 2500° F. The unit is designed to provide 200,000 lb of steam per hour, continuous, at 250 psi at 525° F.

"CONNECT WITH TWECO"



CABLE SPLICERS

A permanent splice to repair broken welding cables. Install with a wrench (or solder if desired) for a quick and efficient connection. Insulated with a tough fiber sleeve. 3 sizes for cable #6 through 4/0. Use TWECO cable connections to improve your welding efficiency.

See Your Welding Supply Distributor

Tweco PRODUCTS COMPANY

TWECO PRODUCTS

Boston at Mosley
WICHITA, KANSAS

Silver Anniversary of Forged Seamless Welding Fittings

This month marks the silver anniversary of one of the most important advances in piping history. It was on July 19, 1927, that Tube Turns, Inc., was incorporated and forged seamless welding fittings were made available for directional changes in piping systems.

These superior fittings, *the first to be manufactured in the U. S.*, have virtually revolutionized industrial piping practices. They have made possible safer, stronger, more efficient piping systems. They save erection time and valuable industrial space, reduce maintenance costs and represent a wise investment wherever piping has a key role.

Since Tube Turns, Inc., was founded 25 years ago, it has grown into a major industry. The company's general offices, main plants and engineering and research facilities are located in Louisville, Ky. There are branch offices in principal cities, and there is a branch plant in Los Angeles. Tube-Turn welding fittings and flanges are stocked and distributed by industrial supply houses in all industrial areas of the U. S. and Canada.

In 1948, Tube Turns, Inc., purchased the Pennsylvania Forge Corp. of Philadelphia, one of the nation's leading manufacturers of forged steel flanges. And, in 1948, a subsidiary, Tube Turns of Canada Ltd., was established in Chatham, Ont.

George O. Boomer is president of Tube Turns, Inc.; John G. Seiler is executive vice-president.

Safety Congress

The 40th National Safety Congress and Exposition will be held October 20-24 at Chicago, Ill. Sessions on industrial safety are scheduled for the Conrad Hilton, Congress, Morrison and Sheraton hotels; traffic safety sessions at the Congress Hotel; commercial vehicle, transit and farm safety sessions at the La Salle Hotel; school safety sessions at the Morrison Hotel, and home safety sessions at the Conrad Hilton Hotel. For further information write R. L. Forney, General Secretary, National Safety Council, 42 N. Michigan Ave., Chicago 11, Ill.

St. Louis Metallizing Co. Formed

The Nooter Corp. of St. Louis, custom fabricators of steel and alloy-plate processing equipment, have announced the establishment of the St. Louis Metallizing Co., to be located at 625 S. Sarah St. Formerly the Metallizing Division of the Nooter Corp., the newly formed company will retain the same personnel, equipment and management.

The metallizing process (by which molten metal is sprayed onto metallic and nonmetallic parts) permits worn machinery parts to be restored to original dimensions for many years of renewed life, applies corrosion and contamination-resistant metallic coatings to vessels, structures, boats, etc. Sprayed metal coatings are also used in the manufacture of plastic molds, corrosion-resistant processing equipment and in the decorative field.

In addition, the new company will offer two other important industrial services: hard surfacing and plastic coating. Hard surfacing is the application of wear- and corrosion-resisting alloys by oxy-acetylene, shielded arc, automatic arc or inert arc methods of welding. Plastic coating is the application of plastic sheeting or liquid films to various types of processing equipment, to serve as barriers to corrosive media.

The management of the new company will be headed by Walter B. Meyer, President (Member of AWS).

Engineering Laboratory Welding Engineer

Graduate Engineer with two to four years' experience in resistance and fusion welding to assist in aircraft design applications, processing problems and development work. Should be acquainted with types of welding equipment used on ferrous and non-ferrous metals and able to correlate design and metallurgical requirements with processing methods.

NORTH AMERICAN EXTRAS—Salaries commensurate with ability and experience • Paid vacations • A growing organization • Complete employee service program • Cost of living bonuses • Six paid holidays a year • Finest facilities and equipment • Excellent opportunities for advancement • Group insurance including family plan • Paid sick leave • Transportation and moving allowances • Educational refund program • Low-cost group health (including family) and accident and life insurance • A company 24 years young.

WRITE TODAY—Please Write us for complete information on career opportunities at North American. Include a summary of your education, background and experience.

NORTH AMERICAN AVIATION, INC.

Engineering Lab Personnel, Dept. E-7

4300 E. Fifth Ave., Columbus, Ohio

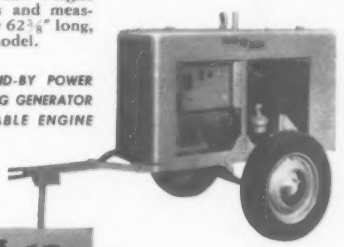
North American has built more airplanes than any other company in the world

NEW ENGINE-DRIVEN D-C WELDER with A-C power take-off

The new Westinghouse Engine-Driven Welder was developed for construction and field-maintenance operations. It provides 200 amperes of d-c current for welding. It also provides 3,000-watt, 110-volt, a-c current for stand-by power. By simply plugging into convenient receptacles on the a-c power panel, the operator may obtain power for drills, grinders, pumps, lights and other electrical equipment.

The standard unit is skid mounted for truck transport or may be mounted on a high-speed, pneumatic-tired trailer. Ready for field service, the unit weighs only 1,150 pounds and measures 39½" high by 62⅝" long, in the stationary model.

★ *CONVENIENT STAND-BY POWER*
★ *IMPROVED WELDING GENERATOR*
★ *EFFICIENT, RELIABLE ENGINE*



J-21713

YOU CAN BE SURE...IF IT'S Westinghouse

WELDING EQUIPMENT

FOR MORE INFORMATION

Write to the Westinghouse Electric Corporation, Welding Division, Buffalo, New York, or contact your nearest Westinghouse representative.

NEW LITERATURE

Addenda Errata Booklet Issued by Tube Turns

Tube Turns, Inc., has recently released an *Addenda Errata Booklet* covering revisions intended to bring their Catalog No. 211 up to date. For your copy, write to Tube Turns, Inc., Louisville 1, Ky.

Welding Analyzer

The new Brush Welding Analyzer, which graphically records welding current, electrode force and other variables in both single- and three-phase resistance welding, is described in a single-sheet catalog of The Brush Development Co., Instrument Division, 72F, 3405 Perkins Ave., Cleveland 14, Ohio.

Fluorescence Analysis

A new 4-page folder, titled "X-ray Fluorescence Analysis, Non-Destructive Testing at Shop Level," is available gratis from the Research & Control Instruments Division, North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

Amply illustrated, the folder is a reprint of an article published recently in a technical magazine. It describes the use of high intensity X-ray tubes and high-efficiency Geiger counters for nondestructive identification of elements in 3 to 5 min after specimens are prepared.

Of particular value are two drawings, one of which shows the basic geometry and operating principle and the other, a typical fluorescent chart as semiautomatically recorded for a chrome-nickel plating on a silver-copper base metal.

Low-Hydrogen Electrode Stabilizer

A 4-page bulletin, describing and illustrating the Blueweld Lo-Hydrogen Electrode Stabilizer, has recently been published by Fred C. Archer, Inc., 606 W. Wisconsin Ave., Milwaukee 3, Wis. Copies may be obtained by writing directly to the company.

Standard Die Catalog for Sheet Metal Work

A new 32-page *Standard Die Catalog*, designed for quick reference by sheet metal fabricators, has just been issued by Federal Machinery Co., 134 Grand St., New York 13, N. Y. Copies of this catalog are available upon request to the Sales Department of this company.

Some Properties of Low-Carbon 8½ Nickel Steel

The paper "Some Properties of Low-Carbon 8½ per cent Nickel Steel" describes a ferritic steel that is resistant to the embrittling effects of low temperatures (−320° F) and which can be welded and fabricated under somewhat the same conditions as engineering steels. 20 tables and charts depict the mechanical properties and the effects of heat treating and welding. Though low-carbon 8½% nickel steel is of special interest to petroleum refining and chemical processing fields, corrosion resisting applications are suggested for it in oil well, pulp and paper, machine tool and other industries. Copies of this article may be obtained by writing to International Nickel Co., Inc., Dept. EZ, New York 5, N. Y.

New Airco Reprint on Cutting Equipment Materials

"Oxygen Cutting of Defense Equipment Materials" is now available as a reprint (Form ADR 78) it was announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc.

This article, which originally appeared in THE WELDING JOURNAL is designed to be of assistance in the development of specifications and procedure control for the proper, economical and accurate cutting of various kinds of steel used for defense equipment materials.

Copies of this reprint may be secured by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Corrosion Protection

A large public utility company solved a tough maintenance problem with metallizing. Underground conduits maintained by this company are practically immersed in water for a large part of each year. Average paint job, used previously, would last from six months to a year before it flaked off. In the meantime, rusting had taken place under the coat of paint during this period.

The first of these conduits was metallized with pure zinc over two years ago, the zinc being covered with a vinyl aftercoat in accordance with specifications of an anticorrosive system. Careful periodic inspections have failed to reveal any apparent change in the metallized coating during this two year period. Even when the vinyl aftercoat fails, which may conceivably occur after five years or so, judging by its present condition, the zinc coating will still be there to provide complete electrolytic protection against corrosion. After this extended time, it will only be necessary to replace the vinyl aftercoat. Even this operation will be inexpensive compared to the replacement of previous paint jobs, since there will be no rust or paint flake requiring removal by the usual wire brushing or sandblasting, comparatively expensive procedures.

Several other money-saving metallizing applications are also discussed in the current issue of *Metco News*, Vol. 6, No. 2. Send for your copy by writing to Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

X-Ray Protection Design

The National Bureau of Standards has recently issued Handbook 50, *X-Ray Protection Design*.

This 36-page booklet contains primary factual data and basic principles necessary for designing shielded X-ray installations, based on the recommendations of the National Committee on Radiation Protection. It considers the protection requirement for persons working with the equipment and for persons in the adjoining areas. It discusses typical cases, giving a variety of examples to illustrate the application of the fundamental principles and recommendations, and carrying out detailed calculations showing how to arrive at the optimum conditions providing sufficient protection, for safe operation with the most economical form of radiation shielding. Practical criteria for the choice of barrier materials, location of X-ray equipment, etc., are included.

Copies of NBS Handbook 50 may be purchased by writing to the Superintendent of Documents, Washington 25, D. C. Price is 15 cents.

Weldment Cleaning

Bulletin 864 on the airless blast cleaning of large weldments has just been published by American Wheelabrator & Equipment Corp., S. Byrkit St., Mishawaka, Ind. Included is a detailed and illustrated case study on weldment cleaning at a large midwestern company together with figures showing the cost savings effected.

Copies of this bulletin may be obtained from the manufacturer upon request.

Tool and Die Salvage Welding

The fourth of a series of "How-To-Weld-It-Better" manuals is *Tool & Die Salvage Welding*, a 64-page, profusely illustrated book on latest welding developments and techniques in this specialized field.

Over 100 photos, drawings, charts and diagrams are devoted to a detailed discussion of more efficient and more widespread usage of improved tool and die welding procedures. Contents are arranged under such descriptive chapter headings as: "Problems in Welding Tool Steels," An Effective Tool and Die Welding and Salvage Program," "Tools Which Can Be Successfully Welded and Salvaged," "New Methods in Production Welding of Tools," etc.

Copies of the new *Tool & Die Salvage Welding* manual may be obtained without charge upon request to Eutectic Welding Alloys Corp., Department "P", 172nd St. at Northern Blvd., Flushing New York 58, N. Y.

Multi-Hydromatic Resistance Welding Equipment

A 48-page catalog of resistance-welding equipment was recently produced by the Multi-Hydromatic Welding and Manufacturing Co.

This book, available to production and metal fabricating management, is completely descriptive of units, machines, fixtures and presses produced by Multi-Hydromatic. Profusely photographic, the catalog presents each item of equipment accompanied by specifications and indicates the job application of each machine, fixture and press.

The Multi-Hydromatic firm produces air and hydraulically operated resistance upsetting, rocker arm spot welders, projection welders, portable welders, hydromatic welders, multiple transformer welders, fixtures and presses.

When requesting a catalog or further information, write to Multi-Hydromatic Welding and Manufacturing Co., 23171 Groesbeck Highway, East Detroit, Mich.

Bronze Welding Rod

A new leaflet describing EutecRod 148 FC, a new bronze welding rod with a special flux coating, has been released by Eutectic Welding Alloys Corp., Flushing, L. I., N. Y.

The special flux coating used on this new alloy is claimed by the manufacturer to be capable of revolutionizing bronze welding since it permits the alloy to bond "automatically" even on dirty cast iron, minimizing possibility of weld failure, of great help in delicate repair jobs.

New leaflet TIS 997-P, containing complete specifications and technical data is available upon request from Eutectic Welding Alloys Corp., 172nd St. and Northern Blvd., Flushing, New York 58, N. Y.

Corrosion Testing Procedures

Corrosion Testing Procedures, by F. A. Champion, 369 pages. Price $6.25. Published by John Wiley & Sons, Inc., 440 Fourth Avenue, New York 16, N.Y.

an ACCO product
for Stainless Steel WELDING
AC-DC Electrodes
GAS Welding Rods
made by
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BURNING...
stable even at lower heats
SLAG...
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resists cracking down to very short stubs
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PAGE Welding Electrodes AND Rods

PERSONNEL

H. M. Oshry Named Vice-President and Director

H. M. Oshry has been named Vice-President and Director of the Crawfordsville Foundry Co., Crawfordsville, Ind. Mr. Oshry has been a member of the AMERICAN WELDING SOCIETY since January 1947.

Rozet Joins Weldwire Co., Inc.

Dr. David Rozet has joined the Weldwire Co. in Philadelphia, Pa., as Vice-President and Director of Research. Previously he was employed for more than nine years by the Arcos Corp. in Philadelphia. Since his graduation with a D.Sc. degree at the University of Brussels (Belgium) in 1936, Dr. Rozet has been active on both sides of the Atlantic in various phases of research on coatings of arc-welding electrodes. His chief specialties are welding metallurgy, and physical and analytical chemistry.

Tenney Engineering Appoints Kielb Production Manager

Tenney Engineering, Inc., Newark, N. J., announces the appointment of Joseph V. Kielb as Production Manager of both its Newark plants. These plants produce chambers for testing products under variable environmental conditions. Kielb will be in charge of all test chamber production including planning and scheduling, plant personnel, production methods, coordination with engineering and sales, and other phases of production management.

Mr. Kielb has a B.S. in Engineering from Bucknell University and has completed special engineering courses at Brooklyn Polytechnic Institute, Syracuse University and the University of Minnesota.

He is a member of the American Society of Refrigeration Engineers, American Society for Tool Engineers, American Society for Metals, Society for Automotive Engineers, and AMERICAN WELDING SOCIETY (past-chairman, Syracuse Section). Also, he has contributed numerous articles to technical journals.

Hallstein New Regional Manager

Appointment of Harold A. Hallstein, Jr., as regional manager of the Nelson Stud Welding Division of Gregory Industries, Inc., with headquarters at the Cleveland branch office has been announced by L. C. Barr, Vice-President and General Sales Manager. In this capacity, Mr. Hallstein will coordinate field engineering and sales activities for Ohio, western Pennsylvania, upstate New York and West Virginia.

Mr. Hallstein, a graduate of Denison University, joined the Nelson organization as a field engineer in Cleveland in 1946, after serving as a First Lieutenant in the Ordnance Department. Prior to his army service, he was associated with Truscon Steel Co. as a sash engineer. He is a member of the AMERICAN WELDING SOCIETY.

Carruthers Made Sales Manager

Robert C. Carruthers was appointed assistant sales manager, welding products, of American Manganese Steel Division, American Brake Shoe Co., at Chicago Heights, Ill.

Mr. Carruthers is a graduate of Massachusettes Institute of Technology. He started with American Brake Shoe in 1950 as metallurgical assistant, and was sales development engineer with American Manganese Steel Division prior to his appointment as assistant sales manager. He is a member of the American Foundrymen's Society, the AMERICAN WELDING SOCIETY and the American Institute of Mining and Metallurgical Engineers. In World War II he was a Lt. (jg.) in the Naval Air Corps.

Yurasko Appointed Supervising Engineer

Frank H. Yurasko has been appointed Supervising Engineer in the Esso Engineering Department of the Standard Oil Development Co., it has been announced. In his new position, he will be head of their Materials Inspection and Expediting Division.

Saves on power costs under load — and during idle and no-load periods!

Cuts maintenance costs and downtime delays — has no moving parts to wear out!

Protects the primary input line against unbalanced conditions!

New P&H DC Rectifier Welder with Dial-lectric Control

. . . Gives you economy, quiet operation, balanced-line loading, and instantaneous remote control

Now . . . you get low-cost DC welding current without a generator, from this new P&H DC Rectifier Welder — industrial twin to the famous P&H AC Dial-lectric Welder.

No troublesome mechanical devices to control amperage — simply turn a single radio-type knob. There are no moving coils or cores to cause delays and maintenance expense — no bearings, brushes, commutator, brush riggings, etc. to replace.

P&H extra-value features like these make this DC Rectifier a real buy: Thermal overload protection. Weather-proof housing. Primary line switch. Range switch. Remote control receptacle. Forced air ventilation. Hinged side covers. Heavy-duty lifting eyes.

New P&H Rectifiers are coming off the production line now. Two sizes: 200 and 300 Amps at 40 V. Be among the first to enjoy the savings this P&H welder helps you realize on power consumption and maintenance. Order your P&H DC Rectifier Welder today.

Ask your P&H representative or distributor for further information on this outstanding unit.

Here's low-cost DC welding power at its best — the P&H DC Rectifier Welder. Note the sturdy construction and absence of moving parts.

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Bronzes, or
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Get in touch with:

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NW Cor. Emerald & Hagert Sts.
Philadelphia 25, Pa.
Phone: GArfield 3-1232

Mr. Yurasko, who was Assistant Supervising Engineer in the Materials Inspection and Expediting Division in the Elizabeth office, is a graduate of Temple. He joined the Esso Engineering Department as a materials inspector and, during most of World War II, represented the company in Washington expediting material for the construction of war plants. Immediately after the war, he spent some time in the Materials Laboratory of the Esso Engineering Department. He was appointed a Group Head soon after joining his present organization. Mr. Yurasko is President of the New Jersey Section of the AMERICAN WELDING SOCIETY and is this organization's representative on the Technical Societies Council of New Jersey. In addition, he is a member of the American Foundrymen's Association.

OBITUARY

Cecil C. Willis

Cecil C. Willis, Superintendent of Generation for Oklahoma Gas and Electric Co. the past 11 years, died on the morning of June 27th at Oklahoma City from a heart ailment. He was 53 years old and had been with Oklahoma Gas and Electric Co. for 30 years. He received a degree of mechanical engineering from Kansas University in 1922 and was a member of the American Institute of Electrical Engineering and the AMERICAN WELDING SOCIETY.

Mr. Willis joined the SOCIETY as an Associate Member on Sept. 30, 1937, and was an active member until the time of his death. He was Secretary of the Oklahoma Section 1939–40, Vice-Chairman 1940–41 and Chairman 1941–42.

Employment Service Bulletin

Position Vacant

V-273. High-type manufacturer's agent calling on welding distributors midwest, mid-south to sell highly accepted apparatus and supplies—established accounts most areas.

Services Available

A-269. Recent graduate with Masters in Metallurgy. Experience in arc, gas and automatic welding. Worked as tooling engineer on welding jigs. Also have taught welding for 2 yr at a leading university. Married and have one child. Willing to go nearly anywhere.

SEACO

• REDUCE Maintenance Costs!
• REDUCE Down-time!

Hard-Surfacing WELDING ELECTRODES

A single pass of SEACO allows parts to workharden and therefore last longer. It takes the toughest impact and abrasion—much longer than many of the more expensive brands. SEACO gives you more for your money, too—only 5% coating and 95% metal. Use SEACO over MANGANAL 11% - 13½% Manganese Nickel Steel build-ups. SEACO makes MANGANAL last up to 50% longer! Try it on your next job!

FREE
Literature on latest methods for speedy and economical repair of worn equipment.

•

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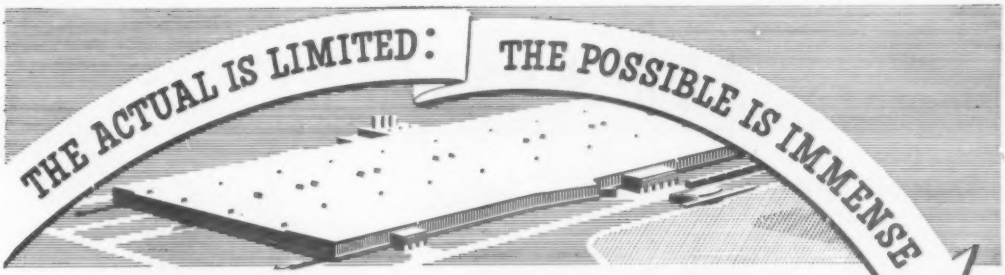
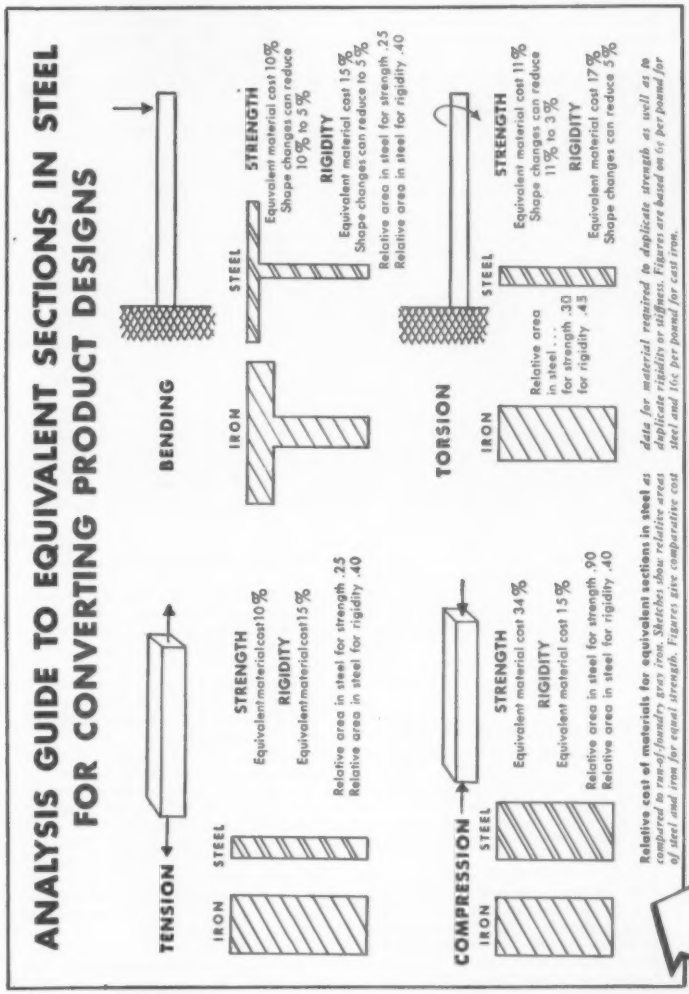


NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

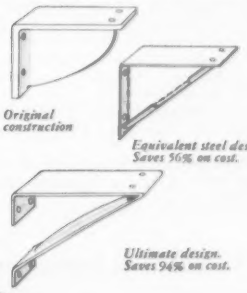
© LE Co. 1952.


ANALYSIS GUIDE TO EQUIVALENT SECTIONS IN STEEL FOR CONVERTING PRODUCT DESIGNS
BENDING
TENSION
STEEL
IRON
STRENGTH
Equivalent material cost 10%
RIGIDITY
Equivalent material cost 15%
Relative area in steel for strength .25
Relative area in steel for rigidity .40
STEEL
IRON
STRENGTH
Equivalent material cost 10%
Shape changes can reduce 10% to 5%
RIGIDITY
Equivalent material cost 15%
Shape changes can reduce to 5%
Relative area in steel for strength .25
Relative area in steel for rigidity .40
TORSION
COMPRESSION
STEEL
IRON
STRENGTH
Equivalent material cost 34%
RIGIDITY
Equivalent material cost 15%
Relative area in steel for strength .90
Relative area in steel for rigidity .40
STEEL
IRON
Relative area in steel ...
for strength .30
for rigidity .43
STRENGTH
Equivalent material cost 11%
Shape changes can reduce 11% to 3%
RIGIDITY
Equivalent material cost 17%
Shape changes can reduce 5%
Relative cost of materials for equivalent sections in steel as compared to run-of-foundry gray iron. Sketches show relative areas of steel and iron for equal strength. Figures give comparative cost data for material required to duplicate strength as well as to duplicate rigidity or stiffness. Figures are based on 6¢ per pound for steel and 1½¢ per pound for cast iron.

PROPER DESIGN IN WELDED STEEL IMPROVES PRODUCT AND LOWERS COST

The chart, at left, shows what relative areas in steel will carry similar loads in machine components built of run-of-foundry gray iron. Whenever product designs follow these values, material costs can be cut to 15% simply by substituting the correct amount of steel and without changing shape. Ultimately where the product is correctly shaped to use steel most efficiently, material costs may be reduced to 5% of the casting cost.

The designs below illustrate potential savings on simple machine parts with steel design. Material for the original design weighs 39 pounds, costs $9.10. However, by using the correct amount of steel, the weight is cut to 12 pounds and cost to $3.97. Changing the shape from a solid section to a formed channel cuts the ultimate weight to 9 pounds and material cost to $.58.



HERE'S HOW

Machine Design Sheets are available on request. Designers and Engineers write on your letterhead to Dept. 98.

THE LINCOLN ELECTRIC COMPANY

CLEVELAND 17, OHIO

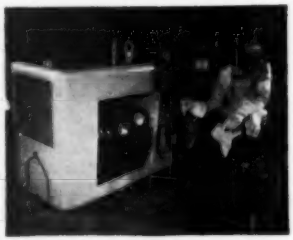
The World's Largest Manufacturer of Arc Welding Equipment

NEW PRODUCTS

Engine-Driven Welder Also Supplies Auxiliary Single-Phase Power

A new light-weight, compact, engine-driven welder (Type EW-20) is available from the Westinghouse Electric Corp. Equipped with complete engine accessories and auxiliary apparatus, the new welder also can supply 110-v, 60-cycle, single-phase power from a conventional plug-in outlet.

Nominal rating of the welder is 200 amp, 40 v, 60% duty cycle with current range from 40 to 250 amp in accordance with NEMA standards. During off-welding periods, auxiliary power of 3 kw at 100% power factor or 2 kva at 80% power factor are available for lights and power tools. During welding periods about 300 auxiliary power is available for lights.



Compact engine-driven welder

Coupled to a Ford "120," 4-cycle, 4-cyl water-cooled industrial power unit, the self-excited, compound-wound generator functions both as a d-c generator and a single-phase alternator for auxiliary power. Welding current is controlled in four ranges by a tap switch and shunt field rheostat. The a-c power circuit includes conventional outlets, a voltmeter and a breaker with overload protection.

For portability, two-wheel running gear suitable for high-speed road towing is available.

For further information write Westinghouse Electric Corp., Box 2099, Pittsburgh 30, Pa.

Electric Cable Repair Kit

Supplementing the "Fast Fix" Oxy-Acetylene Hose Repair Kit which met with such success, Gas Arc Supply, 223 N. 16th St., Philadelphia 2, Pa., has introduced a new "Fast Fix" kit for on-the-job repair of electric welding or power cable. The "Fast Fix" Cable Repair Kit contains all necessary tools and replacement parts for (1) putting new lugs on #14 through #6 power cable, and (2) splicing or putting new lugs on #6 through #4/0 welding or ground cable.

Foote Announces Rutile Substitute

Foote Mineral Co., processors of minerals and ores, announces a new product "Tanarc" as a substitute for critically short natural rutile. Tanarc, containing approximately 70% titanium oxide (TiO_2) is a specially compounded material which is being successfully used in many industrial applications formerly requiring rutile, including electrode-coating materials.

For further information on this material, write Foote Mineral Co., Philadelphia 44, Pa.

"EB" Silver Brazing Alloy

Handy & Harman, New York, has announced the development of a new metal-joining composition to be known as "EB" Silver Brazing Alloy. It is primarily intended for use in brazing chromium carbide, cast carbides and other "hard-to-wet" carbides. Effective results, the company reports, have also been obtained on high tungsten-copper alloy, cer-mets and other refractory alloys difficult to braze.

The new alloy is composed of 57% silver, the balance of the composition includes copper, manganese and tin. It has a melting point of 1120° F and a flow point of 1345° F.

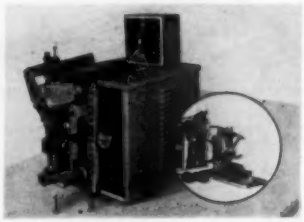
There are no volatile elements in this alloy, an important factor in vacuum applications, and it is nonsusceptible to dezincification type of corrosion. It has been successfully used on Type 316 stainless steel subject to dilute mineral acid corrosion. This does not imply a general recommendation for corrosive service but does indicate a quality which may prove useful when evaluated by tests under actual service conditions.

Powerful Resistance Spot-Welding and Soldering Machine

Joyal Products, Inc., of Newark, N. J., announces the availability of its new Resistance Spot-Welding and Soldering Machine (Model 5000 WVS), equipped with timer.

This machine speeds production, cuts costs, eliminates shrinkage in the manufacturing of instruments and is invaluable to the manufacturer of small, metal products. It solders or welds in less than a second larger and heavier parts than those handled by Model 1000 and 2000.

This machine also silver solders, soft solders and spot welds precious and dissimilar metals. It spot welds steel parts up to $^3/_{16}$ in. thickness; spot welds copper to bronze, copper to copper up to 0.040 in. and brass to brass up to 0.080 in. It will solder brass up to $^1/_4$ in. in thickness as



well as sterling silver and other precious metals.

The set-up time for the various production operations is simple and rapid. Electrodes are especially designed for each job. Their operation is spring-action controlled so that, when electrode arms are closed, work is held firmly in position during soldering and cooling.

An automatic cut-off timer regulates soldering time. Heat control with 11 adjustments determines correct heat for the job. When dials are set, uniform soldering time, heat, and holding pressure on the electrodes are maintained, regardless of how long work is held between jaws. Thus, all chance of work burning and consequent shrinkage is eliminated.

For additional information and catalog material on the new Joyal Resistance Spot Welding & Soldering Machine, please write to Joyal Products, Inc., 56 Belmont Ave., Newark 3, N. J.

Surface Resistance Indicator

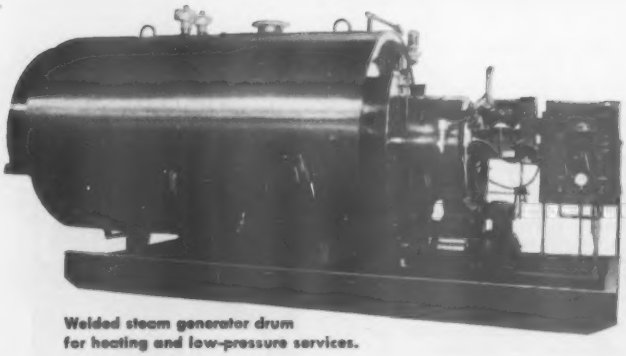
Weltronic Co. announces the availability of a device to measure the surface electrical resistance, directly in microhms, as a criterion of the effectiveness of a cleaning process.

It was primarily designed for measuring the resistance of aluminum; however, other materials with low-surface resistance may also be measured.

According to the Weltronic Co., the indicator can *directly* measure the total surface resistance of two sheets, or coupons, when placed between two self-contained electrodes. Resistance values of 0 to 100 microhms can be read *directly*. Resistance of 100 to 1000 microhms may be read indirectly. Resistance as low as one-millionth of an ohm (0.000001) can be measured on a direct reading *linear* scale calibrated 0 to 100 microhms.

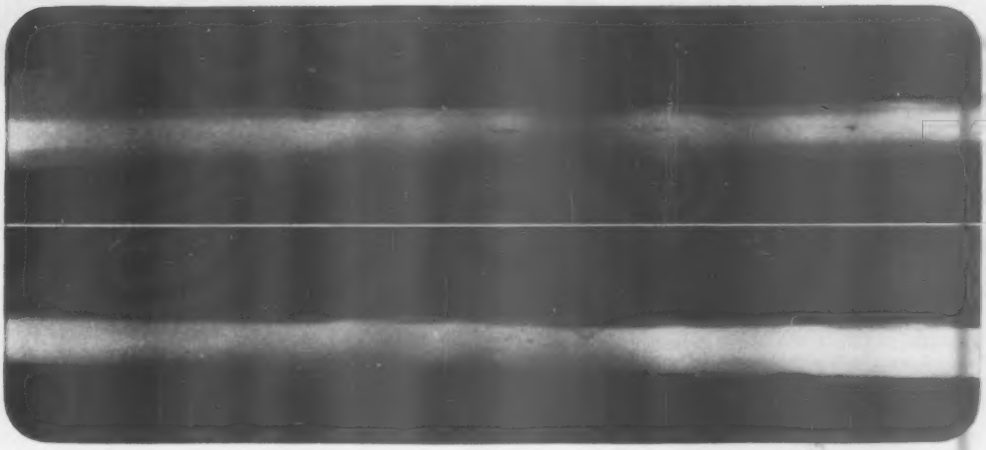
The Surface Resistance Indicator shown in accompanying photo contains a V- or C-type yoke to accommodate aluminum sheet or large coupon. The distance between center of press and bottom of yoke is $5^1/_2$ in.

The indicator is complete with hydraulic pressure device and pressure gage, 3-in. standard copper electrodes, vacuum-tube type d-c millivoltmeter, resistance-indica-



Welded steam generator drum
for heating and low-pressure services.

Dependability up—cost and weight down—



thanks to RADIOGRAPHY

BECAUSE radiography proves it sound, welding can be used for making better pressure vessels. And with results such as these: In these steam boilers approximately 15% in weight was saved—costs dropped 10% to 20% dependent on design pressure.

Easy to see, isn't it, how radiography opens new fields for welding—why it increases business.

Radiography is quick to detect any serious lack of fusion or gas porosities in a weld. It can help you make sure only top-quality work leaves your shop.

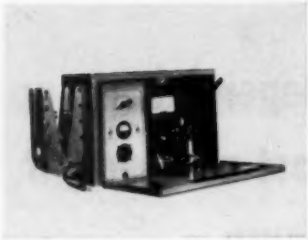
If you would like to know more about how it can help you, get in touch with your x-ray dealer and talk it over.

EASTMAN KODAK COMPANY
X-ray Division • Rochester 4, N. Y.

Radiography . . .

another important function of photography

Kodak
TRADE-MARK



tor adjuster, and d-c power source with suitable voltmeter and indicator bulb. Components are mounted and interwired in cabinet 13 in. high, 20 in. wide, 10 in. deep.

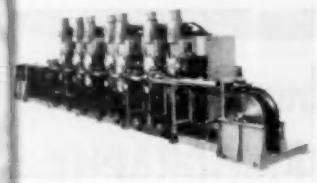
The unit is available shock mounted on caster type cart. Over-all dimensions with cart, 48 in. high, 24 in. wide, 18½-in. deep. Shipping weight complete, 200 lb.

The d-c source consists of standard 6-v, 100-amp/hr automotive storage battery. A suitable battery charger is supplied, mounted and interwired.

The indicator is intended to be a shop- or service-type unit. For further information write for Bulletin No. 40 to Weltronic Co., 19500 W. Eight Mile Road, Detroit 19, Mich.

Multiple-Seam Welder for Joining Aluminum to Aluminum

The Taylor-Winfield Corp., of Warren, Ohio announces the development of a new multiple-seam resistance welder for a leading refrigerator manufacturer.



This welder makes the liner for the cold wall of the low-temperature refrigeration compartment by welding aluminum to aluminum. As the 0.032 gage, 13 x 60-in. plate travels through this machine, six formed aluminum channels, ⅜ in. wide by 60 in. long with ½-in. legs are welded to the plate in a simultaneous operation.

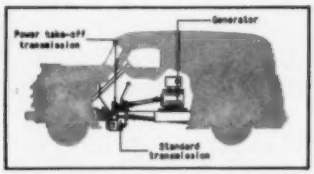
These channels hold metal tubing through which refrigerant passes. By this means heat is extracted from the low-temperature compartment into the refrigerant.

A time-saving feature claimed for this welder is the multiple high-speed wheel dressing unit which removes the aluminum picked up on the copper welding wheels. Supposedly, this is the first time equipment of this type has been available to users of resistance welders.

The entire welder is 32 ft long. One operator and one assistant can load and unload at each end of the machine. The approximate rate of operation is 120 panels per hour.

Tangen Power Drive

The Tangen Power Drive, a new type of power take-off unit recently announced by Mobile Power, Inc., of Detroit, is now being used by several organizations, including manufacturers of mobile welding equipment, according to Charles F. Cummins, president.



One of the advantages claimed by Mobile Power, Inc., for its product is that it is possible to mount this power take-off directly on top of the regular transmission in the truck. No V-belts or pulleys are required. The power drive is capable of delivering 97% of the truck engine power that is transmitted direct from the main gear drive in the transmission. The speed of the power drive shaft is in direct relation to crankshaft speed regardless of the gear ratio being used in the transmission.

For further information address Mobile Power, Inc., 3020 E. Grand Blvd., Detroit 2, Mich.

Special Mask

A special mask to provide eye and respiratory protection against gases and

metallic fumes during welding and burning operations now is employed in the plate shop, South Works, Wyandotte Chemicals Corp., Wyandotte, Mich. (Courtesy of Mine Safety Appliances Co.)

Positive and Negative Slope Control

Weltronic Co. announces the availability of a control accessory designed for the more exacting critical welding applications involving aluminum, magnesium and dissimilar metals. Its use is recommended whenever MIL-W-6860 specifications must be met. Known as Positive and Negative Slope control, it is available as an accessory, as shown in attached photograph, or as a built-in feature.

Slope Control is beneficial in reducing tip pickup, thus permitting many more welds before electrodes must be cleaned. Expulsion and splatter is materially reduced.

This Synchronous Precision Control provides NEMA 7B or 9B Sequence Timer, Phase Shift Heat Control and Slope Control designed to give a slope of the current at the beginning of weld time, a fixed level heat current value during a

Buy "PROVEN FLUXES"

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"ANTI-BORAX" FLUXES

Insist on them — Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
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No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
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Mfg. By
ANTI-BORAX COMPOUND CO., INC.
Fort Wayne, Ind.

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Welding & Cutting Equipt. & Machines
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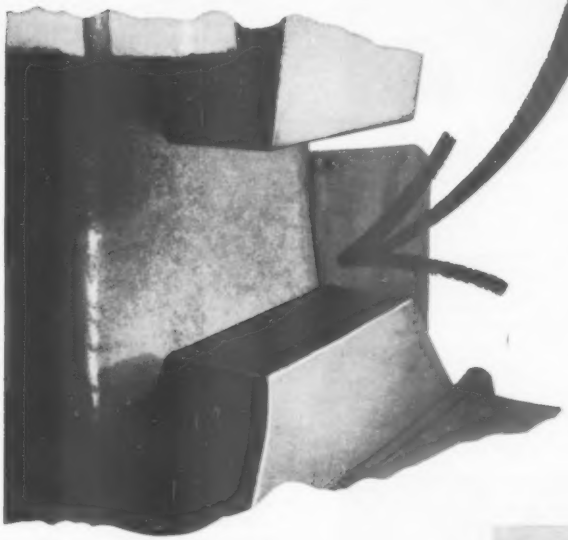
BURDOX

FOUR TIMES THE LIFE...

AND THESE HARD-FACED DIES ARE STILL GOOD



Flat dies formerly used in this blacksmith hammer had to be replaced every three months. Now the dies are protected with a 1/16-in. deposit of HASTELLOY alloy C. The ones shown here have already been in service for over a year, and are expected to last for six to eight months more.

Because the hammers are used almost constantly in a busy steel mill, unprotected dies wore to about 1/2-in. concavity in just three months' time. Then they had to be scrapped and replaced. When the dies that are hard-faced with HASTELLOY alloy C finally do wear, they can be machined and faced again.

HASTELLOY alloy C has been applied with outstanding success to many other hot-working parts. The alloy rod flows easily. No preheating or peening is necessary. Deposits can be machined with conventional die-sinking tools.

For information on how to apply HASTELLOY alloy C to hot-working parts, write for a copy of "HAYNES Hard-Facing Manual." For on-the-job help, write or phone our nearest District Office.

← These hard-faced flat dies have already outlasted four unprotected ones. They are expected to outlast two to three more parts before requiring additional facing.

HAYNES TRADE-MARK *alloys*

"Haynes" and "Hastelloy" are trade-marks of Union Carbide and Carbon Corporation.

Haynes Stellite Company
A Division of
Union Carbide and Carbon Corporation
UCC
General Offices and Works, Kokomo, Indiana
Sales Offices
Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

portion of the weld, and decays the current at the end of the weld.

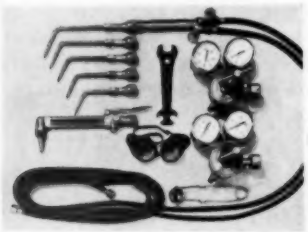
Adjusters to control the current values of (1) Initial Heat, (2) Maximum Heat, (3) Final Heat, as well as the Rate of Increase and Rate of Descent, are furnished.

Control is available with 600 or 1200 frame contactor. Over-all cabinet dimensions are 62 in. high, 24 in. wide, 15 in. deep.

For full information and oscillograph recordings of current variations using Positive and Negative Slope Control, write for Bulletin No. 41. Address Weltronic Co., 19500 W. Eight Mile Road, Detroit 19, Mich.

Welding and Cutting Equipment

A new Model "G-K" series of welding and cutting equipment, capable of handling every job normally done in repair, maintenance and light industrial work, has been added to the Marquette Manufacturing Co. line, Morgan H. Potter, Vice-President and Sales Manager, has announced.



Newly designed and engineered, the "G-K" series is intended for the medium price range, according to the manufacturer.

The Model G welding torch and tips and model K assembly are available either in complete outfits or as individual items.

Air-Movers

To remove fumes and sparks from welding operations, compressed-air type ventilating Air-Movers may be employed. These devices have reportedly, proved to be more satisfactory than a permanently installed ventilation system.

The convenience of portability of the M.S.A.-Lamb Air-Movers permits welders to put them close enough to welding operations to remove practically all fumes and sparks, discharging them into the upper atmosphere of the building (see Figs. 1 and 2). Although the Air-Movers are nearly 3 ft long, their total weight of only 5 lb is largely in the base so that they stand readily in almost any position. This flexibility in handling the ventilating device on the job makes it easy for workmen to use it to best advantage either outside or inside of large weldments.

Fig. 1

No maintenance is required for the Air-Movers. There are no moving parts, motors, turbines or fans. This minimizes explosion hazards in handling dust, gas-laden or heated atmospheres.

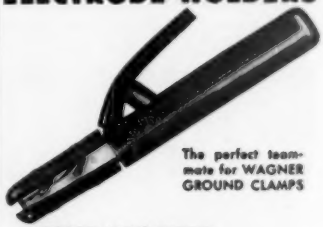
Operation is based on venturi effect produced when compressed air (or steam) is expanded at high velocity through an annular orifice and outlet horn. When operated on 20 lb air pressure the smallest models remove more than 4 cfs of air and fumes from the weld zone.

In addition to their use for fume removal, the air-movers may also be used for introducing fresh air into confined areas to cool the atmosphere or to establish safe working conditions.

Three sizes of M.S.A.-Lamb Air-Movers

Fig. 2

WAGNER
ELECTRODE HOLDERS



The perfect teammate for WAGNER GROUND CLAMPS

RESIST ARC HEAT
Copperhead Tip Insulation operate near 6,000° heat.

COOLER
Patented channel construction flushes heat radiation twice as fast.

FULL CURRENT DELIVERED
Wagnerloy Construction results in high conductivity, longer service.

WAGNER MFG. CO.
330 W. 1st SOUTH ST.
JACKSON, MISSOURI

Weld with Wagner

are available. They include 3-, 6- and 10-in. models which can be operated with 20 to 100 lb of compressed air or 15 to 100 lb of steam pressure.

Additional information about the air-mover may be obtained in Bulletin DP-5, available without charge from Mine Safety Appliances Co., Pittsburgh 8, Pa.

Dedicate Budd Tank Plant

The Budd Co., was host on June 27th to 150 prominent civic, industrial, professional and military figures at a luncheon and exhibit marking the dedication of a new military tank parts plant on Fox St. near Hunting Park Ave.

The $6,000,000 facility will be known as Unit 6 of the Company's Hunting Park Plant. Here, hulls and turrets for a new medium weight tank, a development of Army Ordnance, will be machined and welded under subcontract from Chrysler Corp.

Colonel W. K. Ghormley, Deputy Chief, Philadelphia Ordnance District, and Robert T. Keller, General Manager of Chrysler Corp.'s tank manufacturing operations, attended the affair presided over by Edward G. Budd, Jr., President of the company.

Guests inspected the facilities which will turn out the tank hulls and saw an exhibit of products manufactured by Budd

Simplified Precision Welder Control

for easier maintenance and increased dependability

Class 8993 NEMA Type 52H **Synchronous-Precision Controller** available with 600 or 1200 frame contactor. Can be arranged either for side of machine or wall mounting.

DESIGN LEADERSHIP

APPLICATION: *for welding stainless steel, nonferrous metals, and other critical spot welding jobs requiring electronic synchronous-precision control. (Available with current wave shape control auxiliaries for aluminum or alloy metals.)*

DESIGN LEADERSHIP features

Easier Maintenance . . . greatly simplified circuits require fewer tubes and only one operating relay (for the air valve).

Increased Dependability . . . all components designed specifically for industrial welder service. Tube circuits are fail-safe and initiating contacts are in isolated 24 volt circuit which supplies power to the valve relay.

Consistent Accuracy . . . regulated DC voltage on tube control grids compensates for supply fluctuation or tube variations . . . assures timing accuracy.

Greater Accessibility . . . timer, heat control and firing panels designed for easy inspection and maintenance, with quick fasteners and plug connectors.

Write for **BULLETIN 8993**
or consult your nearby **Square D Field Engineer**

SQUARE D COMPANY

Production Line at Budd Company's new $6,000,000 Tank Plant

at its five plants in Philadelphia, Detroit and Gary, Ind. Automobile and truck body components and wheels, artillery shells, plows and other items manufactured by the company were displayed. Included was one of Budd's new all-stainless steel, self-propelled rail Diesel cars.

Huge photo murals added color and impressiveness to the exhibit. The display remained intact for the more than 10,000 employees of the company's Hunting Park and Red Lion plants, who visited the area on June 28th with families and friends.

Machined and welded tank hulls and turrets will begin emerging from the lines within the next 60 days. When full production is reached, approximately 1000 persons will be employed in the new plant.

The building itself has reinforced concrete foundations with structural steel columns and framework. Red brick walls with a stone trim give an attractive external appearance. It is so constructed that it takes maximum advantage of daylight. Hundreds of tinted windows eliminate glare, cut heat and permit free air circulation.

The more than 270,000 sq ft of floor space in the plant, in addition to smaller adjacent structures rapidly nearing completion, will bring Budd's Hunting Park plant area to nearly 3,000,000 sq ft.

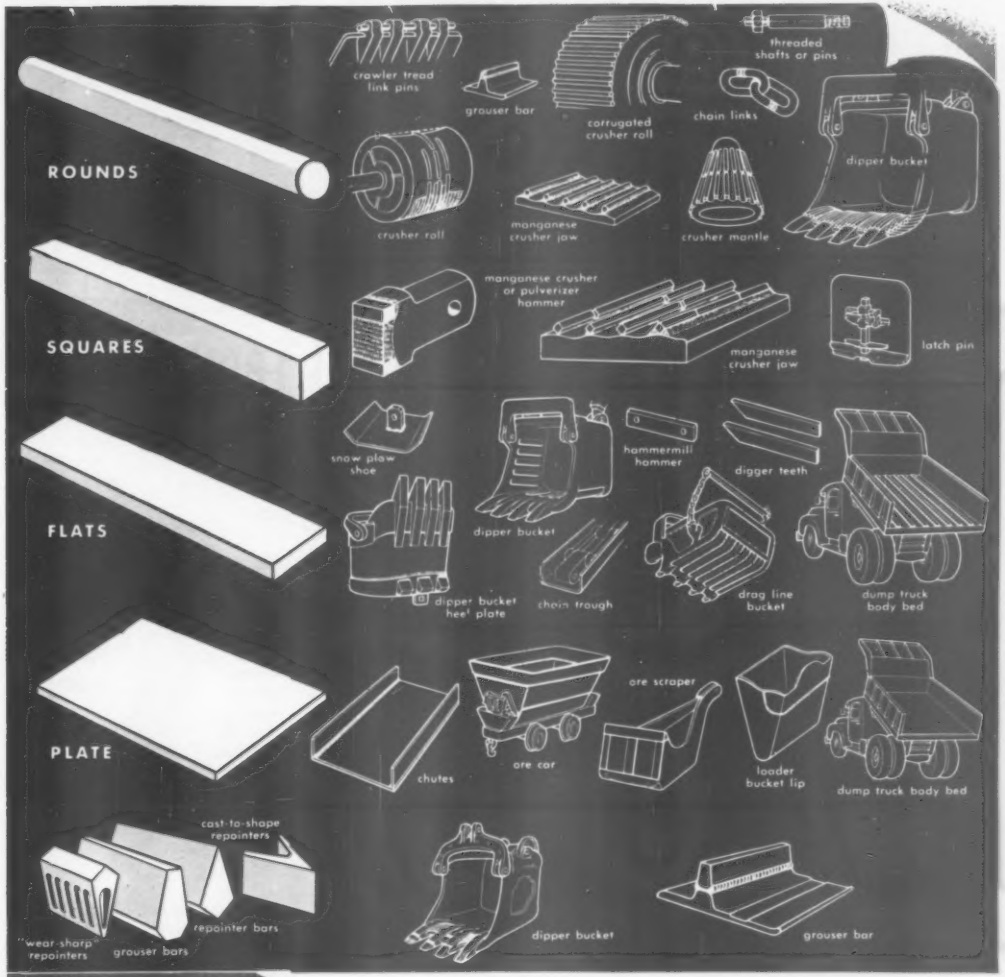
Frank Mallee, who has been associated with The Budd Co. since 1922, is superintendent of the new plant.

Special Welded Trusses Used in Construction of TV Studio

Welding has played a prominent part in the construction of the 230-seat audience

Figs. 1 and 2 The elimination of diagonals from six of the eight panels in these 60-ft welded "Tele-trusses" used by The Austin Co. in the framework of WCAU's new Radio and Television Center has greatly facilitated the installation of walkways and equipment above the three large TV studios. All are 60 ft x 80 ft with 20 ft clearance below the trusses

AMSCO MANGANESE STEEL WELDMENTS
ADD NEW LIFE TO WORN EQUIPMENT



Amsco Welding Rods and Electrodes For repair welding of manganese steel shapes to worn equipment, American Manganese Steel Electrodes retain their toughness and give real operating savings.

Amscoating with Amsco Hardfacing Rods increases service life . . . reduces shutdowns.

Contact your Amsco Distributor or write for illustrated catalog WA-77 on Amsco Manganese Steel Weldments and Hardfacing Selector Guide.

Brake Shoe **AMERICAN MANGANESE STEEL DIVISION**
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Other Plants: New Castle, Del., Denver, Oakland, Cal., Los Angeles, St. Louis. In Canada: Joliette Steel Division, Joliette, Que.
Amsco Welding Products distributed in Canada by Canadian Liquid Air Co., Ltd.

participation TV studio at WCAU's new radio and TV center in Philadelphia. The Austin Co. engineers and builders of the studios, have used special 60-ft. welded tele-trusses without the usual diagonals in the framing for three 60 x 80 ft TV studios and six smaller studios, to provide greater flexibility in the installation of overheat facilities and equipment. (See Figs. 1 and 2.)

Welding Analyzer

The Brush Development Co. has placed on the market a new direct writing Welding Analyzer which records single-phase and three-phase resistance welding machine variables. Welding current and electrode force are measured and recorded simultaneously, and show the important squeeze, weld, "hold" and "off" time intervals. The new analyzer also records the small 180 cps component present in the three-phase welding machine current when ignitron rectifiers are used. The welding machine can be adjusted as the measurements are being made, due to the immediate availability of the information on the direct writing oscillograph.

A detailed description of the Welding Analyzer Model BL-213, may be obtained from The Brush Development Co., Instrument Division, 72E, 3405 Perkins Ave., Cleveland 14, Ohio.

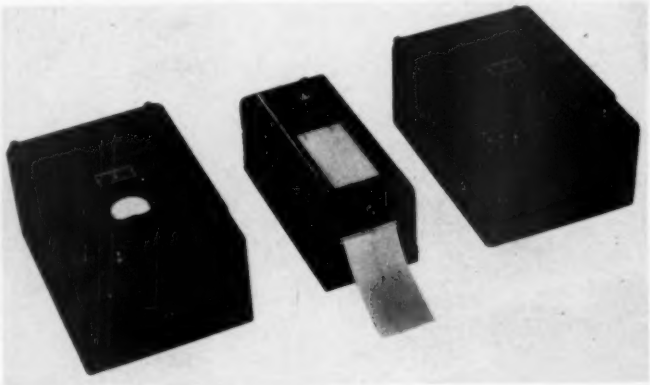
Eliminating Porosity

Spekalaminite Co. of Ossining, N. Y. has announced Weld-Aluminite, a new fusing agent and deporosite, which extends the application of inert arc welding to rimmed steel producing sturdy, quality welds *free from porosity*.

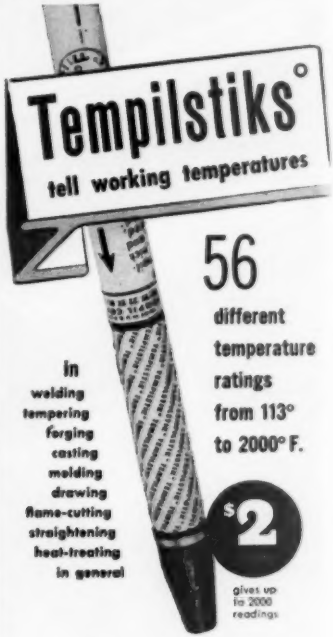
Weldaluminite contains aluminum which deoxidizes the weld pool and is so formulated that it retains the aluminum at the point of welding. No gas bubbles rise to the surface of the pool to cause turbulence. As a result, porosity is eliminated—the arc is stabilized.

Weldaluminite is either sprayed or brushed on the joint to be welded and allowed to dry before welding is begun. It may also be forced-dried, if necessary.

Information may be had by contacting Spekaluminite Co., 100 S. Water St., Ossining, N. Y.



Welding Analyzer


Tempilstiks®
tell working temperatures
56
different temperature ratings from 113° to 2000° F.
in welding tempering forging casting molding drawing flame-cutting straightening heat-treating in general
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gives up to 2000 readings
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WELDING CONNECTORS

Saxe Welding Connection Units position and secure structural parts to be welded.

Clip K3A permits an adjustable connection.

These widely used units eliminate all hole punching, and, with welding, produce the most economical, safe, and quickly erected structural frame.

Write for 1951 edition, Structural Welding Practice Manual.

J. H. WILLIAMS & CO.
Buffalo 7, N. Y.

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UNITED STATES TESTING COMPANY, INC.

INSPECTION and TESTING of Welding and Weldments

QUALIFICATION of Procedures and Operators

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NEW TESTED and PROVED Development...

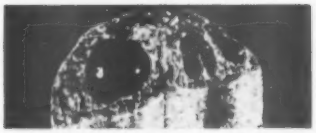
. . . SOLVES POROSITY Problems in INERT ARC WELDING!

WELDALUMINITE

The Welding 'Deporosite' That Amazes Industry!

WELDALUMINITE DOES ALL 3:

1. **Ends Porosity!**
2. **Eliminates need for Filler in many Welding Operations!**
3. **Stabilizes the Arc!**



WITHOUT WELDALUMINITE — Photomicrograph of cross-section view of a weld on Rimmed Steel, without the application of WELDALUMINITE. Note the excessive porosity . . . an extremely weak weld . . . will finish poorly.

WITH WELDALUMINITE — Photomicrograph of cross-section view of a weld on Rimmed Steel with the application of WELDALUMINITE. Note the solid, sturdy joint . . . a top quality weld . . . free from porosity.

WELDALUMINITE, the amazing new 'Deporosite', eliminates porosity problems in Inert Arc Welding. Tested and Proved, the use of WELDALUMINITE on Rimmed Steel produces a perfect weld simply and easily . . . the same uniformly fine-grained structure . . . the same sturdy, high-quality welds as obtained with Aluminum "killed" steel!

WELDALUMINITE is specially formulated with Aluminum which deoxidizes the weld pool and retains the Aluminum at the point of welding . . . prevents turbulence caused by gas bubbling through the molten pool . . . stabilizes the arc . . . prevents porosity! Now it is possible to use Rimmed Steel and get consistently perfect welds!

WELDALUMINITE is quickly and easily applied . . . either sprayed or brushed on the joint to be welded and allowed to dry, or may be forced-dried, before welding is begun. No filler is needed in many welding operations.

IMPROVES WELD — SPEEDS WORK — LOWERS COST . . .

In manual operations, electrode manipulation becomes unnecessary due to the deoxidizing action of WELDALUMINITE. In automatic operations, expensive rework time is eliminated.

WELDALUMINITE as a 'Deporosite' and fusing agent has solved porosity problems in Inert Arc Welding of Iron, Steel, Stainless Steel and Nickel. Write us describing your welding problems. *(Our specialists are at your service.)*

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FREE!

Send for your free trial can of WELDALUMINITE. Just state the type of work you are doing for complete instructions in your particular application. *Write today!*

SPEKALUMINITE COMPANY 100 South Water Street, Ossining, N. Y.

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,597,959—Welding System—Clyde E. Smith, Warren, Ohio, assignor to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

Smith's patent relates to an electric resistance welding system which has a welding transformer and a rectifier connected to the secondary of the transformer to supply direct welding current. The system includes means for effecting welding pressure and means including a solenoid and energizing circuit therefor for varying the welding pressure during the welding cycle. This energization circuit comprises a capacitor and a grid-controlled gaseous discharge device in series with the capacitor. A source of grid biasing potential is provided for the discharge device and it includes a timing capacitor, a relay operative when energized to initiate a change in the charge on the timing capacitor and means to energize the relay. The relay energization means comprise a controlled discharge device having its control circuit connected across the output of the rectifier referred to before.

2,598,025—Thermochemical Cutting and Scarfing Powder—Robert L. Wagner, Niagara Falls, N. Y., assignor by mesne assignments to Union Carbide and Carbon Corp., a corporation of New York.

This patent is upon an unbonded thermochemical cutting powder primarily comprising metallic iron, carbon less than 0.20% and the balance oxides of iron and silicon and other impurities. The powder is sufficiently fine that substantially all passes through a 100-mesh screen and 70 to 74% passes through a 200-mesh screen.

2,598,076—Arc Welding Mechanism—Oliver R. Smith, Fort Worth, Tex.

In this arc-welding mechanism, a flux container is provided and it has an opening adapted to be positioned on the work to be welded with the flux covering the welding zone of the work. Electrode means are moved through the flux into contact with the work to form a molten deposit of molten metal and flux in the welding zone as the container is moved along the welding zone. Means are disposed adjacent the electrode means to direct a coolant into contact with the deposit to solidify it.

2,598,787—Torch with Concentric Gas Oxygen and Mixture Outlets—Werner H. Haak, Brookfield, Ill.

The patented torch has a central unobstructed passage means providing a small orifice on the longitudinal center line of the torch and intermediate and outer annular passage means disposed concentrically about the central orifice. The intermediate annular passage at the face of the torch is broken up into a multitude of small passages while the outer passage is unobstructed. Means provide a mixing chamber communicating with the central passage and other means provide an oxygen inlet passage and a gas inlet passage in the mixing chamber. Gas inlet passage means communicate with the outer annular passage and oxygen inlet means communicate with the intermediate annular passage.

2,599,045—Resistance Welding Process—George R. Brolaski, San Diego, Calif., assignor to Rohr Aircraft Corp., Chula Vista, Calif., a corporation of California.

A resistance welding machine is disclosed and it includes upper and lower welding electrodes having a high electrical conductance and spaced apart to receive the workpiece between them. A long protective strip of the same material as the welding electrodes is in contact with the top of the workpiece and extends beyond both sides of the upper electrode a distance at least as great as the diameter of the tip of the electrode. The thickness of this strip is greater than the thickness of the workpiece.

2,599,281—Arc Welding—Everett F. Potter, Schenectady, N. Y., assignor to General Electric Co., a corporation of New York.

This arc-welding apparatus comprises a pair of alternating current conductors having opposite polarities when energized from a source of electric current. Electrodes having at arcing temperatures the same but substantially different electron emissivities than the work to be welded so that the arc established between each of the electrodes and the work has a greater electric resistance to current flow with one electrode polarity than with the reverse electrode polarity. Means individually connect the electrodes to different ones of the current conductors. The circuit between the electrodes is completed through work parts positioned opposite to the electrodes which are positioned at substantially the same arcing position from the work. Means are provided for simultaneously establishing arcs between each of the electrodes and the work to produce zones of fusion in the work opposite each of the electrodes.

2,599,613—Welding Resistance—Robert J. Cottingham, Huntington, W. Va., assignor to Clayton Orner, Huntington, W. Va.

This patent is on a welding resistance unit. It has a frame with insulating end boards thereon and a plurality of longitudinally extending resistance coils. The patent primarily relates to special mounting means for the resistance coils.

2,599,751—Welding Process for Joining a Metal Body and a Semiconducting Body Composed of Metallic and Ceramic Material—Hermann Federspiel, Terlano, Italy.

In this process an intimate mixture of a minor component of a metal and a major component composed of a metal oxide and ceramic material form the semiconductive body to be welded to a metal body. The welding process comprises placing the portions of the two bodies which are to be welded together in a closely spaced relation and subjecting the two portions to a welding temperature in the presence of a reducing atmosphere. This welding temperature is maintained until the metal oxide contained in the semiconductive body is transformed into metal in its elemental form and until molten metal of the portions of the two bodies to be welded together forms a joint therebetween.

2,600,481—Grinding Fixture for Welded Tubing—John A. Clyde, Ellwood City, Pa., assignor to United States Steel Co.

This patent covers specialized fixtures for grinding a circumferential portion on a tube, pipe or the like.

2,600,582—Sliding Contact System for Conducting Welding Currents—David Sciaky, Chicago, Ill., assignor to Welding Research, Inc., Chicago, Ill.

This patent relates to an electrical system for conducting high-amperage currents and comprises a stationary member in combination with a vertically movable electrical member in horizontal spaced relation to the stationary member. The means for electrically connecting the members include a pair of conductive bars having surface contact with the members to be connected together and each of such members has an end portion with a flat side thereon to facilitate sur-

1500
2000
1000
2500
NO OIL
OXYGEN
100
80
60
40
20
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sensitive
but not temperamental
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WELDING EQUIPMENT CO., San Francisco 5, California

face contact with the bars. The bars are individually pivotally joined one to each one of the members and include a pivot pin of metal supported on the member and insulated therefrom by a tube of insulating material. Resilient means engage each of the different pivot pins for yieldingly holding the respective bar in surface contact with the member.

2,600,585—Three-phase Welding System with Postheat Control—Julius L. Solomon, Chicago, Ill., assignor to Welding Research, Inc., Chicago, Ill.

This patent relates to a welding system in a welding transformer that has a welding load circuit electrically connected to the output of the transformer and means are provided for producing in the load circuit an impulse of welding current. This welding current impulse is characterized as being of modulated shape consisting of a pulse of welding current followed by a controlled decay of said current for postheating. The load impulse means include phase shift circuits for respectively controlling the magnitude of the welding current and the magnitude of the postheating current. Other means in the system are automatically operative at a predetermined point in the welding operation for rendering one of the phase-shift circuits operative and the other inoperative.

2,600,643—Portable Welder— Wesley Hagelgants, Bazine, Kan.

The portable welding apparatus of this patent includes an upright frame having wheels thereon ending in a drawbar extending forwardly from the frame for connection to a tractor or other member. An offset frame extension projects rearwardly and it has a direct-current generating unit mounted thereon. A pair of speed step-up drive members are mounted on the frame while a shock-absorbing coupling is provided between the current generating unit and one of the drive members. A telescopic driving connection exists between the other drive member and the power take-off on a tractor or the like. A reactor coil is connected to the generating unit and is supported by the frame.

LIST OF NEW MEMBERS

Effective June 1, 1952

ANTHONY WAYNE

Hahn, William F. (B)

ARIZONA

Allison, Edward H. (B)

BOSTON

Bready, John (C)
Callahan, Frank (C)
Jamieson, John (C)
Mayhew, Robert (C)
Myers, Earl (C)
Rosenberg, Julius (C)
Scruton, George (C)
Smith, Irving (C)

CHATTANOOGA

Sitton, H. B. (B)

CHICAGO

Bachand, Jack G. (C)
Burns, Robert J. (B)
Gara, Chester (B)
Koch, Herbert (B)
Miller, George H. (B)
Mitchell, Peter M. (B)

CLEVELAND

Dyer, Ellis B. (C)
Gussett, George, Jr. (B)
Hannum, E. F. (C)
Horn, Edward B. (C)
Ispan, Frank J.(B)
Miller, W. R. (B)
Wehmhoff, John H. (B)
Weissman, Leonard A. (B)

COLORADO

Danyew, B. A., Jr. (B)
McAllister, James L. (C)

COLUMBUS

Pierce, James G. (C)

DAYTON

Hickes, James B. (B)
Jones, Harry C. (C)

DETROIT

Erard, Charles B. (C)
Forbes, Harold E. (B)
Marderosian, Siragan (B)
Satullo, Anthony R. (B)
Weicht, Bruno (B)

EASTERN ILLINOIS

Morris, Everett L. (B)

HARTFORD

Anderson, Robert W. (B)

HOUSTON

Allen, Marvin K. (B)
Blose, Thomas L. (B)
Bumpass, E. R. (C)
Derden, L. E. (C)
Evans, H. C. (B)
Farmer, L. G., Jr. (B)
Payton, William Robert (C)
Pieper, G. A. (C)
Singleton, Clarence T. (C)

IOWA

Bark, Loren (B)
Bradshaw, C. E. (C)
Bryant, Floyd (B)
Carroll, John S. (B)
Conner, W. D., Jr. (B)
Cron, A. D. (B)
Dunbaugh, Walter S. (B)
Engle, V. A. (B)
Faddis, Lewis P. (B)
Fillion, R. A. (B)
Friedel, E. A. (B)
Friedel, L. J. (C)
Horn, Henry H. (B)
House, Harold E. (B)
Hughes, Max (B)
Juline, Earl S. (B)
Kane, Martin W. (C)
KilKenny, Jack T. (B)
King, J. W. (B)
Kuhr, G. E. (C)
Landos, Mitchell S. (C)
Lehmkuhl, John H. (C)
Lowe, Ted C. (B)
Magnuson, John (C)
Martinson, F. W. (C)
Moreland, Dale L. (B)
Murray, Eugene P. (B)
Patzig, M. L., Jr. (B)
Pettit, Lewis F., Jr. (C)
Proudfit, Floyd (B)
Rowe, Lloyd R. (B)
Russell, Merle A. (C)
Rutherford, C. S. (B)
Shapter, David E. (B)
Sherbo, John G. (C)
Signs, James (B)
Snyder, Herbert L. (C)
Sones, James E. (B)
Swanson, S. A. (B)
Taube, Henry (B)
Thebom, Henry A. (C)
Tracy, William D. (B)
Turbot, H. R. (B)
Wagner, J. Ray (B)
Warde, R. D. (B)
Weesner, Wayne E. (B)
Weiss, Max (B)
Wiese, Lee O. (B)

LEHIGH VALLEY

Metz, Gerard W. (B)
Perry, John R. (C)

LONG BEACH

Andries, Ferdinand A. (C)
Walker, Leland (B)

LOS ANGELES

Dalebout, P. (B)
Maloney, Jack T. (B)
Mars, Robert L. (C)
Meredith, Harlan L. (C)

MAHONING VALLEY

Millsop, John A. (B)
Winkle, J. B. (B)

MICHIANA

Tuttle, Elmer J. (B)

MILWAUKEE

Dorau, Clarence (B)
Gruss, William H. (C)
Neeld, Roger (B)

NEW YORK

Ashkinazy, S. B. (B)
Bobarykoff, Nicholas I. (B)
Deal, W. M. (B)
Grogard, Andrew J. (B)
Hershkowitz, Benjamin (C)
Powers, Patrick Justin (C)
Tuncer, Fahri (C)

NORTHWEST

Curtis, Paul D. (C)

OLEAN-BRADFORD

Barnes, Lewis G. (C)

PASCAGOULA

King, Frederick, Jr. (B)

PEORIA

Paine, Ellwood (B)

PHILADELPHIA

Berner, Carl W. (B)

PORTLAND

Grant, Earl J. (B)

PUGET SOUND

Dishman, Charles T. (C)
Glass, George A. (B)
Mallas, John A. (B)

RICHMOND

Renninger, Richard S. (B)

ROCHESTER

Ashton, Earl J. (B)

SAGINAW VALLEY

Bushre, Loyd (B)

ST. LOUIS

Wade, Duane H. (B)

SAN FRANCISCO

Babylon, E. R. (B)
Brandon, George W. (C)
Roberts, Stanley I. (C)

SUSQUEHANNA VALLEY

Holloway, Orville W. (B)

SYRACUSE

Lawrence, Richard A. (B)

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TRI-CITIES

Bentley, Robert E. (C)
Bishop, Samuel G. (C)
Black, P. H. (C)
Butler, A. D. (C)
Campbell, William F. (C)
Caton, H. H. (C)
Coker, Robert P. (C)
Couch, M. L., Jr. (C)
Darby, L. W. (C)
Davenport, J. W. (C)
Devaney, R. E. (C)
Edwards, W. (C)
Farris, Clarence P. (B)
Garrett, Lawrence C. (B)
Gooch, C. H. (B)
Green, A. A. (C)
Green, Fred F. (C)
Jackson, Lewis T. (C)
Jackson, M. C. (C)
Johnson, Tommie (C)
Jones, L. B. (C)
Lindsay, Emmett A. (C)
Martin, C. (C)
McCaig, Earney (C)
McCullough, C. D. (C)
McDonald, George W. (C)
Moore, Joe B. (B)
Moore, Leander (B)
Morris, Charlie L. (B)
Patterson, James H. (C)
Pettus, J. B. (C)
Pickett, Calvin D. (C)
Pickett, Wallace Bruce (C)
Pollard, Ernest L. (C)
Runion, Earl T. (B)
Shannon, W. M. (C)
Skidmore, William Earl (C)
Smith, Fred M. (B)
Teague, E. L. (B)
Walpole, James F. (B)
Weems, Andrew J. (C)
Wells, Fred S. (C)
West, Paul J. (C)
Wheeler, A. E. (C)
Worth, A. F. (C)

WESTERN MASSACHUSETTS

Safford, Alden (B)

WICHITA

Woodmancy, Glenn C. (C)

NOT IN SECTIONS

Walton, Reginald John (B)
Winter, Edward L. (B)

Members Reclassified

During the month of June

SALT LAKE CITY

Carlson, Edwin (C to B)
Christensen, Lynn J. (C to B)

SUSQUEHANNA VALLEY

Howard, Donald B. (C to B)

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Annual Spring Dance

Buffalo, N. Y.—The Annual Spring Dinner and Dance held by the *Niagara Frontier* Section took place on June 6th at Lamm Post No. 622, American Legion, Williamsville, N. Y. Good food and a good time were enjoyed by the 70 couples attending.

Election of Officers

Buffalo, N. Y.—The annual election of officers of the *Niagara Frontier* Section took place at the June 6th meeting with the following results:

Chairman—Robert P. Gehring, R. D. 2, Lockport, N. Y.
First Vice-Chairman—R. Thomas Breymeier, Union Carbide & Carbon Research Laboratories, Niagara Falls, N. Y.
Secretary-Treasurer—Robert Siemer, 97 Florida St., Buffalo, N. Y.
Chairman, Membership Committee—F. Leo Rodgers, Jr., 1527 Main St., Buffalo, N. Y.
Chairman, Program Committee—Gerald E. Claussen, Union Carbide & Carbon Research Laboratories, Niagara Falls, N. Y.
Technical Representative—Richard G. Lyall, 109 Chassin Ave., Buffalo 21, N. Y.

Low-Alloy Steels

Chicago, Ill.—One hundred and six members and guests attended the May 16th dinner meeting of the *Chicago* Section held at the Chicago Engineers Club.

N. C. Jessen, Metallurgical and Welding Engineer, Babcock and Wilcox Co., covered some new facts and developments in the welding of low alloys and stainless steels in power boiler construction. A lively discussion followed.

Cocktail hour preceded the dinner and social period followed the technical meeting. This type of meeting is popular in Chicago and three such meetings are being planned for the coming season.

Annual Golf Tournament

Chicago, Ill.—The Eleventh Annual Golf Tournament and Outing was held at Gleneagles Golf Club on Saturday, June 14th, with the first golfer teeing off at 7:30 A.M. Three hundred and thirty-five members and guests teed off on a perfect golf-weather day. Three hundred and twenty-three remained for dinner after which the prizes were distributed. The attendance was the largest in the history of this event.

Applications of Hard Facing

Dayton, Ohio—E. C. Hurd of the Haynes Stellite Division, Union Carbide and Carbon Corp. spoke extemporaneously on the "Mechanical and Manual Oxy-acetylene and Arc Applications of Hard Facing" at the March 11th dinner meeting of the *Dayton* Section held at the Engineers Club. Mr. Hurd's discussion of the subject also covered other methods of application and were supplemented by a series of slides.

An informal business meeting preceded the technical meeting.

Welded Fabrication

Dayton, Ohio—La Motte Grover, AWS, of the Air Reduction Sales Co., New York, was the guest speaker at the April 8th meeting of the *Dayton* Section held at the Engineers Club. Mr. Grover's talk on "Welding Construction and Maintenance Operations" also covered welded fabrication and construction procedures.

Mr. Grover has been associated with the New York office of Air Reduction during the past 13 years, assisting fabricators, engineers, designers, railroads and shipbuilders in the application of both the arc and oxy-acetylene welding processes. During World War II he was closely affiliated with the control of welding in the shipbuilding industry and served on Advisory Committees of the American Bureau of Shipping, U. S. Maritime Commission and War Metallurgy Committee.

Prior to the technical session an informal business meeting was held at the YMCA.

Picnic

Dayton, Ohio—The annual picnic of the *Dayton* Section was held on June 10th at the Inland Manufacturing Gun Club.

A bang-up program starting with a four-inning softball game was followed by a complete dinner and, as a special treat, a Monte Carlo party was a huge success.

Each picnicker was given a large sum of money which they used in shooting crap, playing chuck-a-luck, blackjack, roulette or poker. At the end of 1½ hours of gambling, valuable prizes were given to the man and woman who accumulated the most money.

One hundred and forty members and guests had a gala time.

Election of Officers

Denver, Colo.—The *Denver* Section announces the election of officers for 1952–53 as follows:

Chairman—V. A. Schroer.
First Vice-Chairman—Herman Geller, Stearns Roger Mfg. Co.
Secretary—Paul C. Mathias, 334 Grant St.
Treasurer—C. Brinton Swift, Linde Air Products Co.

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Chairman, Program Committee—W. D. Hooper, Linde Air Products Co.
Technical Representative—Robert B. Craig, Jr., Hendrie & Bolthoff

Oil Drilling Industry

Denver, Col.—Allen Wisler, AWS, of the Hughes Tool Co., Houston, Tex., gave an illustrated technical talk on "Welding in the Oil Drilling Industry" at the June 10th dinner meeting of the *Colorado* Section held at the Oxford Hotel, Denver.

Party

Fort Wayne, Ind.—The *Anthony Wayne* Section held its final meeting of the season at Howard Johnson's Restaurant in Fort Wayne on June 6th. A grand turkey dinner was enjoyed by the members, their wives and sweethearts

Three very interesting films were shown as follows: "Dust or Destiny," a film of dramatic presentation of inexplicable miracles of nature, was shown through the courtesy of the Moody Bible Institute, Chicago, Ill. This film depicted the wonders of the human ear which miraculously hears the blast of a cannon as well as the soft footfall of a cat and the wonderful mechanism of the heart with its more than 2,000,000,000 beats during an average lifetime without shutdown or repairs. In the animal realm the picture showed the remarkable homing instinct of the pigeon; the flight of the bat, guided by its own radar; and the incredible spawning habits of the grunion, a fish laying its eggs on dry land. This picture was accompanied by sound and in color. It proved to be outstanding. The other two color sound pictures shown were "Colorado River Bass" and "Battling the Rogue River." All three were well received and Robert C. Neeb did a grand job of showing the films for the entertainment for the evening. Fifty-two members and guests attended the dinner party.

Election of Officers

Fort Wayne, Ind.—The results of the recent election of officers for the 1952–53 season were announced at the June 6th meeting as follows:

Chairman—Russell F. McNutt, Sutton Garten Co., Fort Wayne, Ind.
First Vice-Chairman—Virgil S. Beck, Beck Welding Works.
Second Vice-Chairman—K. H. Zimmerman, American Steel Dredge Co.
Secretary—Gerald Springer, International Harvester Co.
Treasurer—D. B. Rice, Sutton Garten Co.
Chairman, Membership Committee—Glen D. Birt, American Steel Dredge Co.
Chairman, Program Committee—Harry M. Johnson, Wayne Welding Supply Co.
Technical Representative—George H. Laws, Ruckman-Hansen Co., 3617 Leo Rd., Ft. Wayne 8.
Board Members for Two Years—Jacob Geiser, Carl Carey, Delbert Clark, Roy Busler, Robert C. McCoy, Gerald B. Evertts.
Board Members for One Year—Elmer Nofzinger, James M. Smith, L. B. Brewer, Rufus Kirchhifer.

Past-Chairman pins were presented by R. F. McNutt to George H. Laws, Ruchman-Hansen Co. (1948–50), Harold Hamilton, International Harvester Co. (1950–51), Harry M. Johnson, Wayne Welding Supply Co. (1951–52).

Inert-Arc Welding

Indianapolis, Ind.—T. W. Eselgroth, Midwestern Regional Service Engineer, Linde Air Products Co., Chicago, Ill., gave an excellent talk on the subject "Inert Gas Shielded Tungsten Arc Welding" at the May 23rd dinner meeting of the *Indiana* Section held at Buckley's Restaurant, Cumberland, Ind. Mr. Eselgroth's talk was accompanied by a film entitled "Study of Arcs in Sigma Welding." Both the talk and film were interesting, informative and explained the process in detail. A question-and-answer session followed. An attendance of 43 were at the meeting.

Election of Officers

Louisville, Ky.—The *Louisville* Section announced the election of officers for the 1952–53 season as follows:

Chairman—Roba Yarbro, American Bureau of Shipping, Louisville, Ky.
First Vice-Chairman—Everett S. Elwood, 441 University Ave., Louisville 6, Ky.
Secretary—E. H. Dilley, Tube Turns, Inc., Louisville, Ky.
Treasurer—Joseph O'Regan, 1864 Overlook Terrace, Louisville, Ky.
Technical Representative—Mason S. Noyes, 218 Fairlawn Rd., St. Matthews, Louisville 7, Ky.

Election of Officers

Newark, N. J.—The *New Jersey* Section announced the election of officers for the 1952–53 season as follows:

Chairman—F. O. Bodine, Midwest Piping & Supply Co., Clifton, N. J.
First Vice-Chairman—N. F. Kiernan, Metal & Thermit Corp., Newark, N. J.
Secretary—R. L. Deily, Washington Rock Rd., R. D. 2, Bound Brook, N. J.
Treasurer—K. Koopman, Development Division, Linde Air Products Co., Newark 5, N. J.
Chairman, Membership Committee—J. E. Gunning, 75 Woodbine Ave., Newark, N. J.
Chairman, Program Committee—A. Steinberger, Monhegan Ave., White Meadow Lake, P. O. Box 381, Rockaway, N. J.
Technical Representative—F. H. Yurasko, 20 Glenside Ave., Scotch Plain, N. J.

Election of Officers

Pascagoula, Miss.—The annual business meeting, election and installation of officers for the coming year took place at the June 4th dinner meeting of the *Pascagoula* Section held at the Shipyard Cafe, this city.

Retiring Past-Chairman, John F. Bryan, Jr., of the American Bureau of Shipping, excellently covered the history of the Pascagoula Section.

With the announcement of the election of officers Earl S. Shulters of the U. S. Maritime Administration was installed as chairman of the meeting.

The newly elected officers are as follows:

Chairman—Earl S. Shulters, P. O. Box 125, Pascagoula, Miss.
First Vice-Chairman—Albert A. Holly, Star Route, Gautier, Miss.
Secretary-Treasurer—Irwin W. Whittemore, 1101 E. Cleveland Ave., Pascagoula, Miss.
Chairman, Membership Committee—John F. Bryan, Jr., American Bureau of Shipping, Pascagoula, Miss.
Chairman, Program Committee—Robert H. Macy, P. O. Box 481, Pascagoula, Miss.
Technical Representative—Thomas J. Dawson, 450 Polk St., Pascagoula, Miss.

Annual Dinner Party

Philadelphia, Pa.—The third Annual Dinner Party and Dance of the *Philadelphia* Section was held at the Engineers Club on May 17th. A most enjoyable evening was had by the members and guests.

The Program Chairman, A. M. (Gus) Garcia planned and directed a splendid program and in addition rendered a number of vocal selections which rated loud applause. Fred Judelsohn, in his usual jubilant mood, did a fine job of leading the audience in a number of old favorite songs in keeping with the fine party spirit. Other high lights of the evening included a separate introduction of Tom Jackson and R. D. Thomas, Sr. Both were presented with a certificate of appreciation for their many years of devoted service to the AMERICAN WELDING SOCIETY and to the welding industry. These awards were presented by K. W. Ostrom, retiring Chairman of the Philadelphia Section, who in turn was presented with an inscribed gavel by the newly elected Chairman, R. A. Guenzel. This Third Annual Party was so well attended that it gave speculation as to larger quarters for next year's party.

Executive Committee Meeting

Philadelphia, Pa.—The Executive Committee of the *Philadelphia* Section held their meeting on June 3rd at the Llanerch Country Club where a number of the officers arrived early in the afternoon and "teed off" for a round of golf prior to the business at hand. It was not made clear who the "Sammy Snead" of the Philadelphia Section might be, but Chuck Middlestead did a mighty fine job on the last hole with the aid of a cottonwood tree.

After a very enjoyable dinner the meeting was called to order by Mr. Guenzel, who briefly reported favorable progress was being made by all committees in connection with the Fall meeting. The committee was honored by the presence of J. G. Magrath and F. J. Mooney, Secretary and Assistant Secretary, respectively, from national headquarters. They eagerly assisted in formulating detailed plans for the current national fall meeting.

Other local officers and committee chairmen in attendance were Ralph Bradway, Thomas Berg, John Lang, Walter Mehl, Byron Gates, W. W. Whitley, A. M. Garcia, J. S. Douglas, K. Wm. Ostrom, R. S. Phair, A. B. Gordon, Frank Gramm, Louis Hauser, R. D. Thomas and A. J. Erlacher.

Plant Tour

Phoenix, Ariz.—The June meeting of the *Arizona* Section was a plant visitation to the Ralph H. Smith Co., of Phoenix, Ariz. Approximately 45 members and guests were present.

Following the buffet dinner, a very interesting tour was made of the plant where various items were hard faced for the group using unique automatic welding machines. The Ralph H. Smith Co. has pioneered the automatic hard-facing process in this area and has developed its own machines for this specialized field. Mining, lumber, tillage and road contractors are very enthusiastic about these facilities to repair and resurface parts such as track rollers of shovels and tractors, also crane wheels. The cost of a rebuilt and resurfaced roller is less than half of a new one and the company guarantees the rebuilt one to outlast a new one, hence the enthusiastic response.

Everyone present agreed that it was an exceptionally fine meeting and the Section is deeply indebted to the Ralph H. Smith Co. for its many courtesies.

Election of Officers

Phoenix, Ariz.—The annual election of officers of the *Arizona* Section held in May resulted in the following:

Chairman—Ralph H. Smith, Ralph H. Smith Co., Phoenix.
First Vice-Chairman—J. August Rau, Allison Steel Mfg. Co., Phoenix.
Second Vice-Chairman—Charles Fogwell, Haywire Welding Works, Phoenix.
Secretary—Walter E. Riley, Riley & Foltz, Phoenix.
Treasurer—F. Morris Aspey, Consolidated Western Steel Corp., Phoenix.
Executive Committee—Edward Allison, John Dyer, William Garland, Phillip Binkley, William Fischer, Hal Savage, Charles Carlson, Edward Thomas and Robert Phares.

Election of Officers

Pittsburgh, Pa.—The *Pittsburgh* Section announced the election of officers for the 1952–53 season as follows:

Chairman—E. H. Turnock, 344 Woodside Rd., Pittsburgh, Pa.
First Vice-Chairman—Wm. H. Kauffman, Sunset Lane, Anderson Rd., Pittsburgh, Pa.
Secretary-Treasurer—J. F. Minnotte, Minnotte Brothers Co., Hays, Pittsburgh, Pa.
Chairman, Membership Committee—A. C. Brown, Jr., Air Reduction Sales Co., Pittsburgh, Pa.
Chairman, Program Committee—Wm. H. Kauffman, Sunset Lane, Anderson Rd., Pittsburgh, Pa.
Technical Representative — Harry L. Anthony, Mellon Institute of Industrial Research, Pittsburgh, Pa.

Election of Officers

Portland, Ore.—The *Portland* Section announces the election of officers as follows:

Chairman—R. L. Howerton.
First Vice-Chairman—Stanton Richardson, Air Reduction Pacific Co.
Secretary—B. N. Wood, P. O. Box 1048.
Treasurer—Paul B. Strech, Morden Machines Co.

Election of Officers

Saginaw, Mich.—The *Saginaw Valley* Section announced the election of officers for the 1952–53 season as follows:

Chairman—Dean L. Knight, National Electric Welding Co., Bay City, Mich.
First Vice-Chairman—M. W. Blackwood, Baker Perkins, Inc., Saginaw, Mich.
Secretary—W. E. Moehring, 2114 Clement St., Flint 4, Mich.
Treasurer—Irving S. Makulinski, 610 W. Philadelphia Blvd., Flint 5, Mich.
Chairman, Membership Committee—James Alcock, Saginaw Welding Supply Co., Saginaw, Mich.
Chairman, Program Committee—M. W. Blackwood, Baker Perkins Inc., Saginaw, Mich.
Technical Representative—Ray J. Ladd, Dow Chemical Co., Midland, Mich.

Election of Officers

Tulsa, Okla.—The *Tulsa* Section announced the election of officers for the 1952–53 season as follows:

Chairman—John Tipton, 1136 E. 49th St., Tulsa, Okla.
First Vice-Chairman—Morris White, National Tank Co., Tulsa, Okla.
Second Vice-Chairman—R. H. Wainwright, Flint Steel Co., Tulsa, Okla.
Secretary—F. L. Silvers, 1228 S. Quebec, Tulsa, Okla.
Asst. Secretary—Ben Walcott, General Electric Co., Tulsa, Okla.
Treasurer—L. F. Douglas, General Electric Co., Tulsa, Okla.
Chairman, Membership Committee—Richard Todd, 712 N. Evanston, Tulsa, Okla.
Chairman, Program Committee—R. M. Church, 1740 S. College, Tulsa, Okla.

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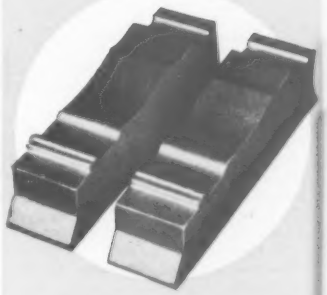

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Technical Representative—W. H. Jaggers, 2731 E. Admiral Court, Tulsa, Okla.

Election of Officers

Washington, D. C.—The *Washington* Section announced the election of officers for the 1952–53 season as follows:

Chairman—Paul Tarver, 12 Elwyn Court, Silver Spring, Md.
First Vice-Chairman—R. H. Evert, Westinghouse Electric Corp., Washington 6, D. C.
Second Vice-Chairman—T. J. Griffin, 308 Holmsrun Rd., Falls Church, Va.
Secretary—R. A. Webster, 7128 9th St., N. W., Washington, D. C.

Election of Officers

Wichita, Kan.—The *Wichita* Section announces the election of the following officers for 1952–53.

Chairman—H. L. Mobely, Coleman Co., Inc.
First Vice-Chairman—O. W. Daniels.
Second Vice-Chairman—W. E. Bush.
Secretary—F. W. Hein.
Treasurer—R. P. Whitt.
Chairman, Membership Committee—P. D. Carter.
Chairman, Program Committee—O. W. Daniels.
Technical Representative—Earl Krasser, 328 S. Belmont, Wichita 8.

Election of Officers

Worcester, Mass.—The *Worcester* Section announced the election of officers for the 1952–53 season as follows:

Chairman—Clifford A. Murray, 344 Brooks St., Worcester, Mass.
First Vice-Chairman—John F. Kenney, Jr., 29 Nola Dr., Holden, Mass.
Second Vice-Chairman—Wesley A. Proctor, Stafford Iron Works, Inc., Worcester, Mass.
Secretary—C. Myron Burnett, 38 Arbutus Rd., Worcester, Mass.
Treasurer—Robert G. Jamieson, 91 Bryn Mawr Ave., Auburn, Mass.
Chairman, Membership Committee—C. Myron Burnett, 38 Arbutus Rd., Worcester, Mass., and Joseph Polaski, 9 Richards St., Worcester, Mass.
Chairman, Program Committee—George F. Wilson, Air Reduction Sales Co., Worcester, Mass.
Technical Representative—John C. Kasabula, 12 Lorenz St., Worcester, Mass.

Plant Visit

Youngstown, Ohio—Sixty-five members of the *Mahoning Valley* Section visited the plant of the Federal Machine and Welder Co., Warren, Ohio, on April 17th.

Plant Visit

Youngstown, Ohio—Fifty-three members of the *Mahoning Valley* Section visited the plant of the Mullins Manufacturing Co., Warren, Ohio, on May15th.

Informal Meeting

Youngstown, Ohio—The *Mahoning Valley* Section was treated to some up-to-the-minute baseball news of the 1952 Cleveland Indians by Jack Cresson of the Cleveland Indian Baseball Assn. at its June 12th dinner meeting held at Cafe 422 in Warren, Ohio.

Election of Officers

The *Mahoning Valley* Section announced the election of officers for the 1952–53 season as follows:

Chairman—R. E. Heltzel, Heltzel Steel Form & Iron Co., Warren, Ohio.
First Vice-Chairman—J. H. Cordner, Westinghouse Electric Corp., Sharon, Pa.
Secretary-Treasurer—W. D. Colbert, Chicago Bridge & Iron Co., Greenville, Pa.
Chairman, Membership Committee—L. Dunlap, 897 Trumbull, Warren, Ohio.
Chairman, Program Committee—J. H. Cordner, Westinghouse Electric Corp., Sharon, Pa.
Technical Representative—Dr. I. A. Oehler, American Welding and Manufacturing Co., Warren, Ohio.

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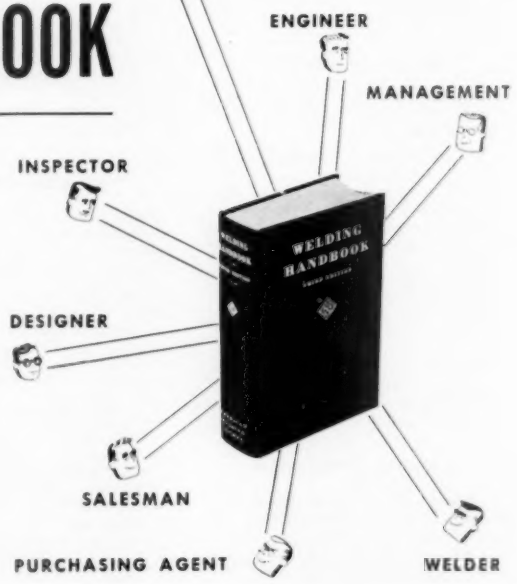

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Supplement to the Welding Journal, August, 1952

Effect of Vibration on Weld Metal

Effect of vibration on the microstructural solidification pattern and on the mechanical properties of AISI Type 321 and 347 steel during both arc and resistance welding

by John W. Welty

DURING the past several years there has been an increasing interest in the possible beneficial effects to be derived from the application of sonic and ultrasonic vibrations to metals under welding conditions. This article will discuss the effect of vibration on the microstructural solidification pattern and on the mechanical properties of AISI Type 321 and 347 steel during both arc and resistance welding.

During 1948 the Research Division of Solar Aircraft Co. began a project to investigate the properties of weldments made under vibratory conditions, and a number of interesting experiments have been completed since that time. It was realized that good qualitative data would be necessary to act as a signpost for the direction that future investigation might take. Therefore, the equipment described and pictured had the prime function of inducing vibration of generally known characteristics upon laboratory test samples so the qualitative data could be gathered by means of mechanical tests and microscopic comparison of metallurgical structure.

Fusion welding experiments were made by means of inert-gas shielded arc methods. In order to eliminate all possible variables, automatic control of current, voltage characteristics and weld time was employed. Typical fusion welding equipment used is shown in Fig. 1. This consists of a high-frequency generator, on the left, with an inert-gas shielded arc welding head riding in a travel carriage shown near the center of the

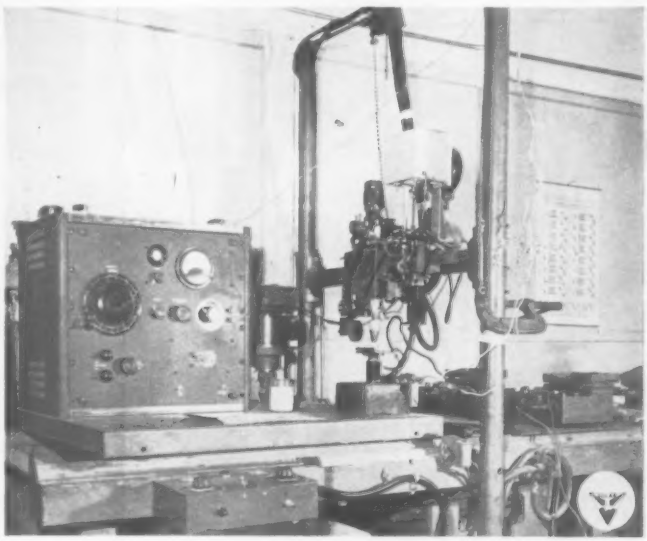

Fig. 1 Setup for vibrated fusion weld samples

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picture. Below this welding head is one of the magnetostriction transducer assemblies used for vibrating the specimens.

Figure 2 is a schematic lineup of the electrical equipment employed. Basically, this equipment is quite simple—from power supply, to frequency generator, to amplifier, to transducer coil which unit induced the mechanical vibration into the test samples. The direct current is supplied to polarize the transducer, thus eliminating the negative half wave. Figure 3 shows the power amplification unit used in this setup.

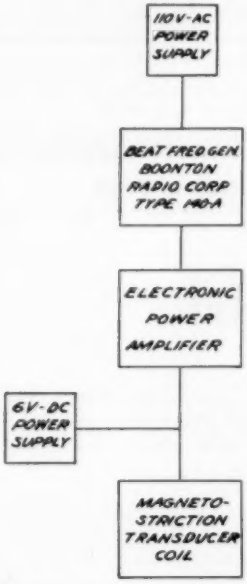

110 V-AC POWER SUPPLY
BEAT FREQ GEN BOONTON RADIO CORP TYPE 140-A
ELECTRONIC POWER AMPLIFIER
6V-DC POWER SUPPLY
MAGNETO-STRICTION TRANSDUCER COIL

Fig. 2 Schematic drawing of electrical set-up for fusion weldments

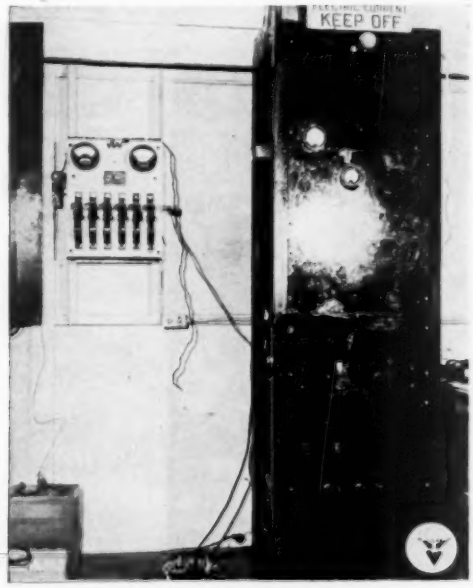


Fig. 3 Power amplifier for the fusion weld tests

In the resistance welding experiments, a troublesome problem presented itself in finding a satisfactory method of measuring or showing the actual vibration characteristics existing in the test sample at the time of welding. A cathode-ray oscilloscope proved useful in recording the general vibration pattern, and this was supplemented by fine grains of round sand sprinkled over the test piece. The sand revealed the vibration pattern and the relative amplitude from grain arrange-

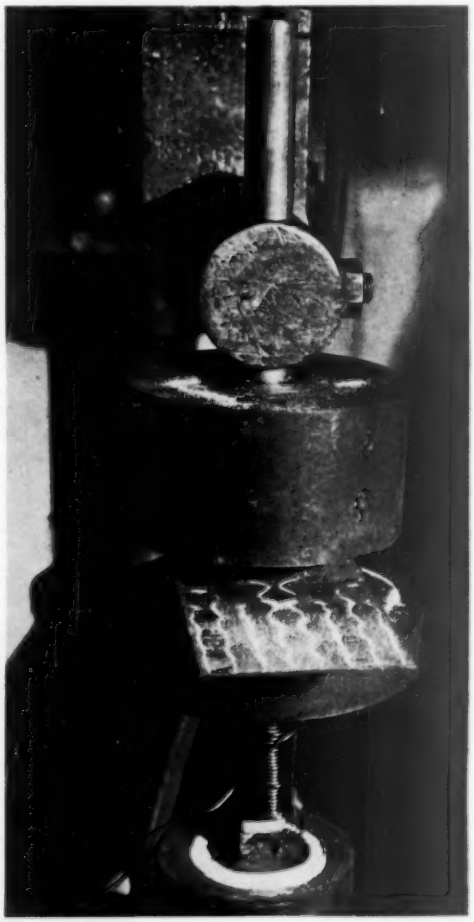


Fig. 4 Sand pattern created by vibration of spot-weld specimen

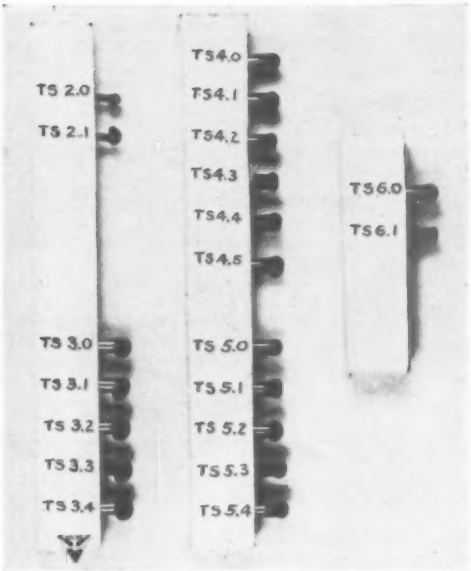


Fig. 5 Fused rod ends sectioned for metallographic examination of solidification patterns

ment and the height of bounce. By this means, we were able to eliminate the possibility of having a test

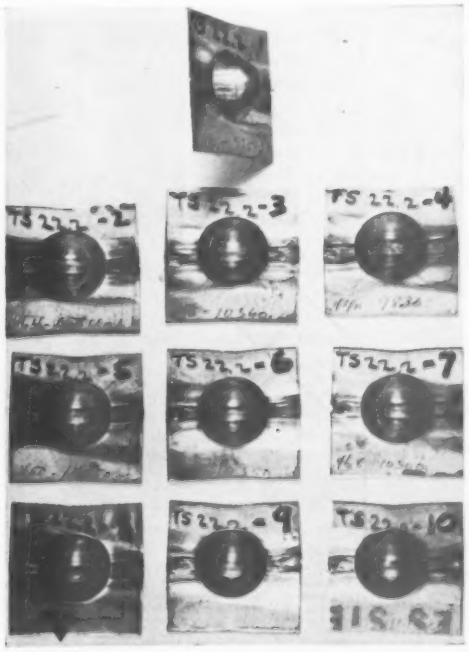
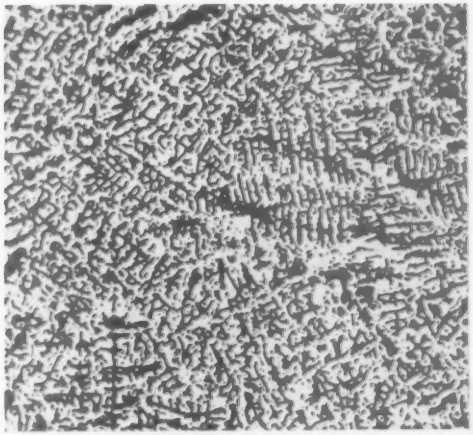
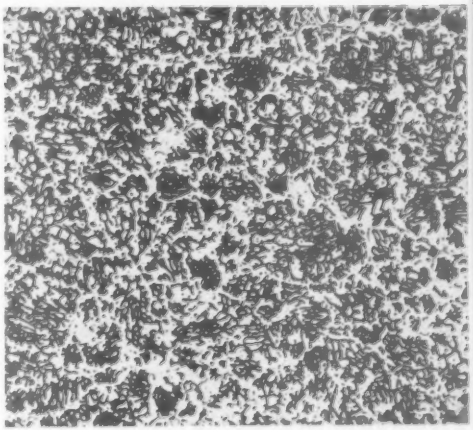


Fig. 7 Cup test specimens



Ts 4.0. Unvibrated. Type 347 stainless steel rod of 1/8 in. diameter



Ts 4.1. Frequency 7.1 kc. Type 347 stainless steel rod of 1/8 in. diameter. No. 4 magnetostriction transducer. No. 4 coil. No. 7 base

Fig. 6 Photomicrograph at 250 × comparing vibrated and unvibrated weld structures

weld at one of the node points of vibration on the sample. Figure 4 shows a sand pattern on a piece of metal being vibrated between spot-welding electrodes. It will be noticed that the sand has arranged itself in a definite pattern over the test piece, although, obviously, the height of bounce cannot be measured from the picture. An Acme spot welder was used in making the vibration resistance weld samples, with vibrations induced in both 10- and 20-cm magnetostriction electrodes.

In the fusion weld experiments, three different types of samples were employed: (1) short lengths of 1/8- and 1/4-in. rod were fused under controlled conditions of vibration and time, and specimens for microscopic examination were made up. This seemed a simple

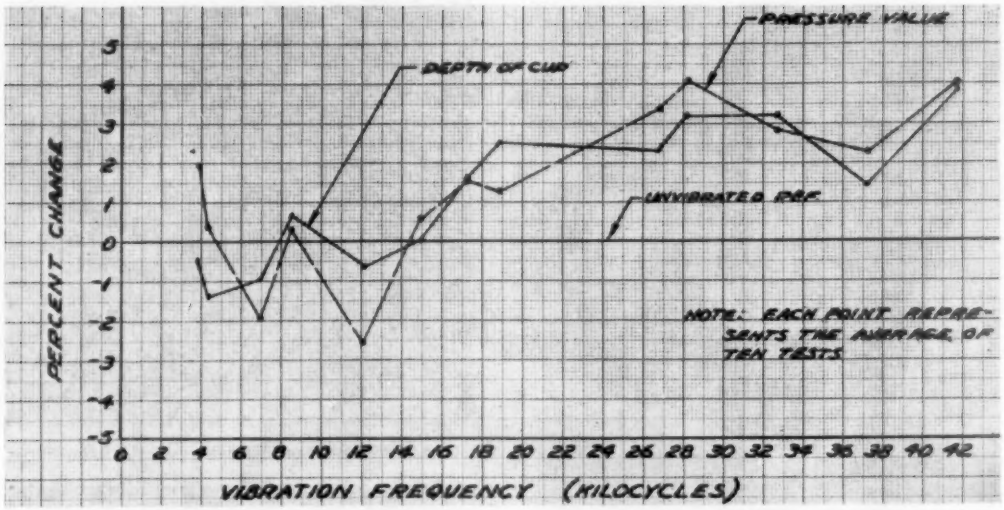


Fig. 8 Curves plotted to show per cent change of load and fracture points at various frequencies
Vibration welding cup test results comparing vibrated vs. unvibrated specimens each having weld bead across middle in per cent change

and accurate way of noting any difference in solidification patterns of vibrated as compared to unvibrated pieces. (2) A weld bead was run across the center of a 3- x 3- x 0.050- sample, with evaluation based on standard cup testing. (3) A similar weld bead was made in a narrow strip of the same material, with a specimen prepared by removing the parent metal from the edges of the bead so that the remaining material had been almost entirely fused during the welding operation. The specimen was tensile tested for ultimate strength, yield strength and per cent elongation.

For examination of the effects of vibration on the solidification pattern, standard metallographic techniques were employed, utilizing a Bausch and Lomb Research Model Metallograph. Examination was conducted at both high and low magnification, the photomicrographs reproduced here being taken at 50 × and 250 ×.

Figure 5 shows the fused ends of rod sections, buttons of which were subsequently sectioned for microstructural examination. In making these samples, cuts through the beads were made in several directions relative to the axis of the rod to be certain that all types of solidification patterns were obtained.

Figure 6, photomicrographs at 250 ×, illustrates, above, an unvibrated weld pattern and, below, a pattern obtained at a vibration frequency of 7.1 kc. The microstructure of the vibrated metal shows a more desirable and random orientation with less dendritic directional growth than does the unvibrated weld. The long, treelike dendrites are almost completely absent in the lower, vibrated, sample. Obviously no mechanical tests could be run on the small weld buttons to correlate microstructure and mechanical properties.

Cup test samples are illustrated in Fig. 7. The technique employed involved clamping the edges of the piece between the platens of the cup tester, then slowly forming the cup across the weld bead by means of a $^1/_4$-in. diameter steel ball. The load at fracture and

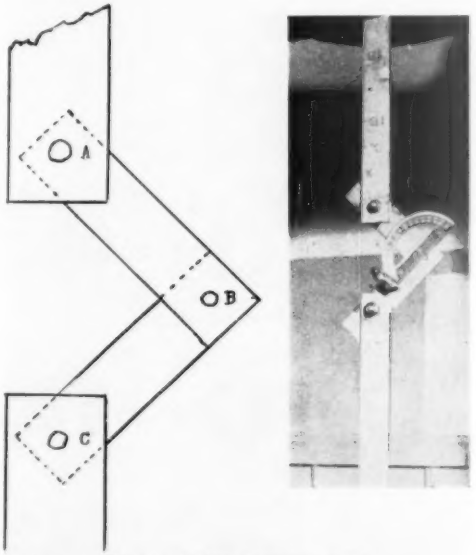


Fig. 9 Torsion-shear test setup

The photograph above shows the Type 347 stainless steel samples spot welded at right angles. By use of the Southwark-Emery tensile machine the spot weld is twisted to fracture through a maximum of 90 deg. A protractor is clamped to the test specimen to indicate angular displacement

Below is a diagrammatic sketch showing the test setup at half scale. To obtain optimum results, all samples are drilled identically. The bolt holes at *A* and *C* are accurately located 3.00 in. from the center of the spot weld, *B*, and at 90 deg to each other. (Distance *AC* is 4.24 in.)

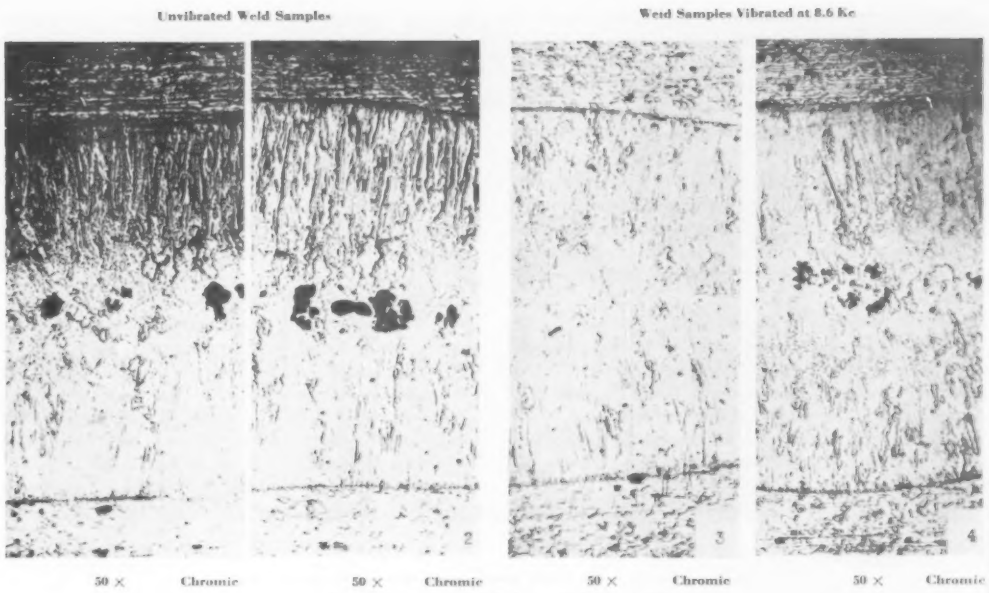


Fig. 10 Micrograph at 50 × of spot-weld nuggets

the depth of the cup were recorded as significant figures and are plotted in the graph, Fig. 8. Here vibration frequency is plotted against per cent change in load and depth of cup, as compared to unvibrated welds. As noted in the graph, each point represents the average load and deformation values computed for 10 samples. For example, the graph shows that at a frequency of 28 kc, the vibrated welds formed 3.2% deeper than the unvibrated welds and withstood 4% more load before fracturing. A study of this graph will reveal that below 15 kc per second, we recorded a slight loss in both the ductility and pressure values of vibrated samples, whereas above this point there is a gain of a few points. The maximum improvement appears in the range of 28 to 32 kc.

The tensile and ductility tests made on weld beads gave almost identical results in the vibrated and unvibrated specimens. A calibrated Baldwin-Southwark machine was used to break the specimens and comparative readings were recorded. The average yield strength of 10 typical vibrated specimens was 38,000 psi, as compared to 39,830 psi for unvibrated specimens. Tensile strength of vibrated samples was 76,980 psi, compared to 76,960 psi for unvibrated parts. The vibrated specimens displayed elongation of 37% compared to 35% for unvibrated parts. A number of specimens were prepared and tested to cancel out any inconsistencies that resulted because of slight differences in sample size and parent metal remaining on the edges of the weld bead.

Specimens for resistance weld testing, all made on an Acme Spotwelder, were 0.050- x $1^1/_4$- x 4-in strips with two strips spot welded at right angles to form the sample. These were tested by a torsion-shear type of loading, as shown in Fig. 9, which is a typical setup used. This shows a single-spot right-angled specimen located between the jaws of the testing machine with a protractor attached for accuracy in measuring the angular displacement at any particular load. The welding current employed in making these samples was 9900 amp with a weld time of $^1/_5$ second at a pressure of 1000 psi. Single spot welds were made in each pair of strips after the strips were carefully positioned and the spot located. Great care was taken in selecting and drilling the strips, and locating the spot in order to insure accurate test conditions.

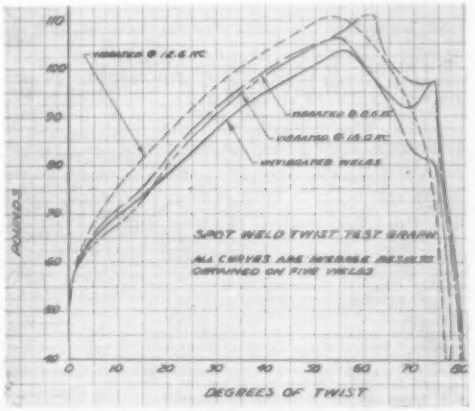


Fig. 11 Torsion-shear results plotted

Examination of a number of the resistance weld specimens by microscopic means showed no significant change in the nugget pattern or metal structure of vibrated as compared to unvibrated welds. However, the vibrated welds seemed to have less porosity and fewer gas holes at the center of the nugget. Figure 10, photomicrographs at 50 ×, illustrates this fact. It is of a series of 4 spot weld nuggets, 2 of which were not vibrated, and 2 of which were vibrated at 8.6 kc. It should be stated that this effect was not always reproducible, but the average porosity of a number of samples examined was less in the case of the vibrated welds.

To show graphically the effect of vibration on the mechanical properties as measured by the torsion-shear test, the curves of Fig. 11 were constructed. These show the pounds of load applied, plotted against the degrees of twist for several different frequencies. The peak loads were obtained in all samples at a displacement of approximately 60 deg. The plotted averages indicate that the vibrated specimens have slightly more torsion resistance than unvibrated specimens.

SUMMARY

Most present-day specifications which are written to control welding base their quality requirements on macro- and microexamination together with mechanical tests to show tensile strength, elongation and torsion values. These are the tests we used in evaluating our vibrated and unvibrated specimens and compiling the data given above.

Although results of tests conducted varied widely, and no great amount of consistency was recorded in the purely qualitative data, the general trend slightly favored vibrated samples and would seem to indicate that further work on vibration techniques for the fusion and resistance welding of AISI Type 347 stainless steel might lead to development of methods which would be of definite benefit to the weld areas.

Seam Welding of 0.005-In. Inconel Sheet

Techniques suitable for seam welding 0.005-in. annealed Inconel were developed through the use of a seam welder having a low inertia head

by E. F. Nippes and John M. Gerken

Summary

The vacuum chamber of a protron accelerator required that the top face be covered with a thin metal or plastic covering having suitable magnetic and dielectric properties. This investigation dealt with the seam welding of 0.005-in. Inconel sheet for this purpose.

It was found that 0.005-in. annealed Inconel could be seam welded using an electrode force of 75 lb with a low inertia moving electrode, a current of 1350 to 1425 amp, a sequence of 1/2 cycle "on" 4 cycles "off" with a 60 cps supply and 40 welds per inch. Electrode wheels of RWMA Group A, Class 2 alloy were used with a 6 in. diameter, and 1-in. radius surface. A special seam-welding machine with a low inertia head was built for this purpose. Double seam welds were made with the second seam at the edge of one sheet to form an effective air seal with a 1/8-in. diam neopreme gasket crossing it at right angles.

E. F. Nippes and John M. Gerken are connected with the Welding Laboratory, Department of Metallurgical Engineering of the Rensselaer Polytechnic Institute, Troy, N. Y.

INTRODUCTION

THE construction of a proton accelerator, called a "cosmotron," at the Brookhaven National Laboratory involved sealing the vacuum chambers with a skin of metal or plastic having desirable magnetic and dielectric properties. The purpose of this investigation was to determine seam welding conditions and a welding technique suitable for fabricating these skin sections from 0.005-in. thick Inconel sheet. Since 12 in. is the maximum width rolled in 0.005-in. Inconel sheet, it was felt that the skin could best be made by seam welding strips of this width.

A 1/8-in. diam neopreme gasket running along the inner and outer periphery of the vacuum chamber forms an airtight seal between the skin and the main chamber. This means that the sealing gasket must cross each weld seam in a transverse direction. In order that no air may leak through the interface between the sheets on the gasket side, it is necessary to run a second weld seam along each joint at the extreme edge of the overlapping sheet. At the same time, this flattens the edge of the overlapping sheet, enabling the gasket to seat better at the weld crossover points. During the welding of the extreme edge seam there is a possibility of the sheets being burned through. Every precaution must be taken to prevent this, since obviously these holes would result in air leaks.

EQUIPMENT

Based on previous experience on the seam welding of high nickel alloys, it was thought that an electrode force of about 100 lb would be necessary to weld 0.005-in. Inconel. The 175 kva seam welder at this laboratory had an upper movable

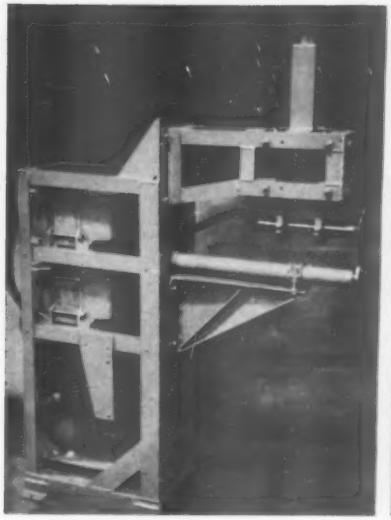


Figure 1

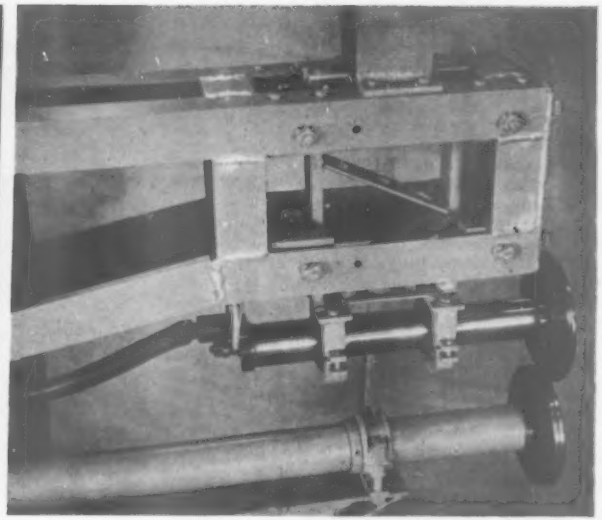


Figure 2

electrode assembly weighing 250 lb. Although this force could be reduced with a counterbalancing spring, it was felt that the resulting high inertia and the inherently high friction of this machine would cause difficulty in making sound welds. For these reasons, a 5-kva seam welder, shown in Fig. 1, was designed and built. The movable electrode assembly, shown in Fig. 2, weighs somewhat less than 25 lb and is mounted in ball bearings to minimise friction. A compression spring provides electrode forces up to 100 lb. Details of the construction of this machine are given in the appendix.

MEASUREMENT OF VARIABLES

Current was measured with a dynamometer type ammeter of 10-amp, full-scale reading connected directly in the primary circuit of the welding transformers. RMS secondary current during the "on" time was computed from the ammeter reading using the following formula:

$$I_{secondary} = I_{meter}\sqrt{\frac{\text{total time}}{\text{"on" time}}}\left(\text{transformer turns ratio}\right)$$

This method of measuring current is satisfactory only when the total weld cycle is short. If the weld cycle is too long the meter pointer will oscillate too much to be read accurately.

The weld sequence was measured on a Brush direct-inking oscillograph and on a cathode-ray oscilloscope.

Electrode force was determined by the amount of compression of the upper electrode spring. The spring was calibrated by exerting the force of the upper electrode on a platform scale.

Speed of travel was determined by the setting of a dial on the Thymotrol unit which controlled the speed of the motor. This dial was calibrated for wheel surface speed with a 6-in. diam electrode wheel in position.

WELDING 0.005-IN. ANNEALED INCONEL

Throughout this investigation electrode wheels made of RWMA Group A, Class 2 were used. These were tapered at the

Fig. 3 Weld made in annealed Inconel with 50 lb electrode force, 1320 amp, sequence 1 "on" 3 "off", 39 welds per inch, welding speed 23 in./min. Note double nugget and porosity. 165 ×. Welding direction →

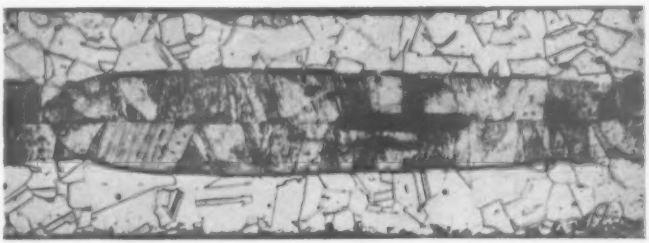


Fig. 4 Weld made in annealed Inconel with 50 lb electrode force, 1075 amp, sequence 1/2 "on" 4 "off," 40 welds per inch, welding speed 20 in./min. Note porisity at this low current value. 165 ×. Welding direction →

periphery to a $^5/_{32}$-in. wide surface with a 1 in. radius turned on it.

Series of welds were first run at 30, 40 and 50 lb electrode force with a weld sequence of 1 cycle "on" 2 cycles "off" on a 60-cycle supply, surface speeds of 23, 27 and 32 in. per minute, and currents from 950 to 1520 amp during the "on" time. It was noted that expulsion occurred at 950 amp with 30 lb electrode force, 1140 amp with 40 lb electrode force and 1330 amp with 50 lb electrode force. Microscopic examination of longitudinal weld sections revealed that weld nugget porosity occurred at currents lower than those necessary to produce a continuous fused weld seam. This effect was more pronounced at 30 and 40 lb than at 50 lb electrode force. It was further noted that each nugget consisted of a small fused zone partially enveloped in a larger fused zone, as shown in Fig. 3. The outer nugget and inner nugget are formed, respectively, on the first half cycle and second half cycle of the single cycle of welding current. There is a time between half cycles when no current is flowing due to the phased-back nature of the current. The second half-cycle weld is smaller because the weld of the first half cycle has already solidified and therefore shunts the current to a considerable extent.

The next series of welds were made at 50 lb electrode force with sequences of 1 "on" 3 "off" and 1 "on" 4 "off" with wheel speeds of 23 and 27 ipm, for each. As with the sequence of 1 "on" 2 "off" at 50 lb electrode force, expulsion occurred at a welding current of 1350 amp, and weld nugget porosity occurred at a current lower than that necessary to produce a continuous fused weld seam.

By referring to Fig. 3, it may be seen that the second half cycle of a single-cycle weld contributes very little to the length of the nugget. Therefore, it was decided to limit further work to $^1/_2$ cycle "on" time. It was also felt that the shorter time would reduce porosity.

With an electrode force of 50 lb, welds were made with timing cycles of $^1/_2$ "on" 2 "off," $^1/_2$ "on" 3 "off," and $^1/_2$ "on" 4 "off." Wheel speeds were adjusted to give 40, 50 and 60 welds per inch for each timing cycle and current was varied from about 900 to 1500 amp. Expulsion was not as pronounced as with the one cycle "on" time; however, porosity was still present, as shown in Fig. 4.

The electrode force was increased to 75 lb in an effort to eliminate the porosity. Seams were welded with this force with weld cycles of $^1/_2$ "on" 2 "off" $^1/_2$ "on" 3 "off," and $^1/_2$ "on" 4 "off" at wheel speeds to give 30 and 40 welds per inch. The examination of the previous welds, made at 50 lb electrode force, indicated that at 40 welds per inch the individual fused nuggets could be made to overlap without difficulty. In addition, seams were also tried with 30 welds per inch to determine whether a greater spacing was practicable.

The increase to 75 lb electrode force reduced porosity to very fine slits parallel to the sheets at the center of some nuggets. The penetration of weld nuggets in seams with 30 welds per inch was only 30% compared with 50–55% for seams made under similar conditions with 40 welds per inch. The seam width for these welds was approximately 0.025 in.

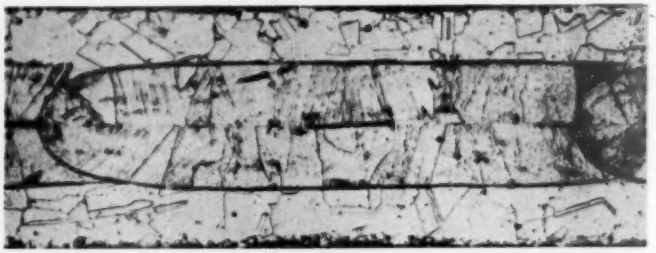


Fig. 5 Weld made in annealed Inconel with 75 lb electrode force, 1420 amp, sequence $^1/_2$ "on" 4 "off," 40 welds per inch, welding speed 20 in./min. 165 ×. Welding direction →

Fig. 6 Weld made in $^3/_4$ hard Inconel at 95 lb electrode force, 1255 amp, sequence $^1/_2$ "on" 4 "off," 40 welds per inch, welding speed 20 in./min. Note recrystallized grains next to fused zone. 165 ×. Welding direction →

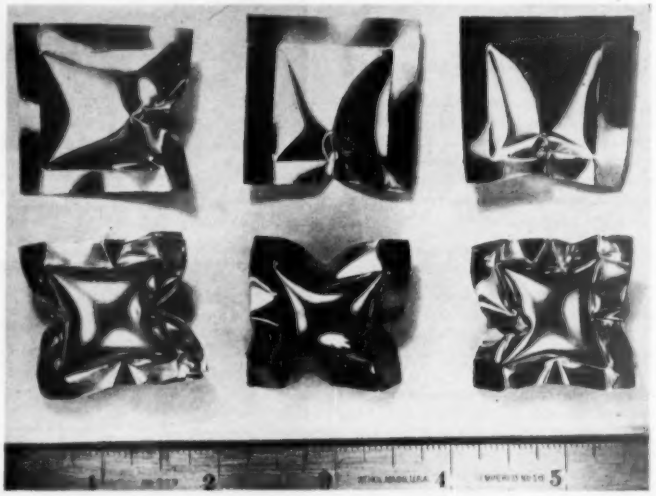


Fig. 7 Pillow tests of seam-welded sheet using dry ice. Top 3—$^3/_4$ hard 0.005-in. Inconel. Failed next to weld. Bottom 3—Annealed 0.005-in. Inconel. Did not fail at room temperature; when heated to about 300° F failed next to weld

There appeared to be slightly less porosity with a weld sequence of 1/2 "on" 4 "off" than with 1/2 "on" 2 "off," or 1/2 "on" 3 "off," and for this reason it was decided to use the 1/2 "on" 4 "off" timing for making the test samples. However, the timing sequence, 1/2 "on" 2 "off," which will permit the fastest welding speed may be desirable for use in most cases.

The conditions for seam welding 0.005-in. thick annealed Inconel are as follows:

Electrode force: 75 lb
Timing cycle: 1/2 cycle "on," 2 to 4 cycles "off" (60-cycle supply)
Surface speed: 20 to 36 ipm
Welds per inch: 40
Current range: 1350–1425 amp
Wheel surface: 3/32 in. wide, 1 in. radius dome, 6-in. diam wheel
Electrode material: RWMA Group A, Class 2

A longitudinal weld made under recommended conditions is shown in Fig. 5.

WELDING 0.005-IN. 3/4 HARD INCONEL

As a start, the recommended welding conditions for the 0.005-in. annealed Inconel sheet were tried on the 0.005-in. 3/4 hard Inconel. These welding conditions resulted in profuse expulsion, indicating that the welding current had to be reduced or the electrode force increased. This expulsion was caused by the increased electrical resistance of the cold-worked sheet and also by the increased contact resistance resulting from the smaller area of contact between the harder and less deformed sheets.

When the welding current was reduced to 1000 amp with 40 welds per inch and 75 lb electrode force, intermittent expulsion was still noticeable. A series of seams were welded with 60 welds per inch and 75 lb electrode force using currents ranging from 700 to 1150 amp. Expulsion was considerable at 1150 amp but was not noticeable at 1000 amp or less. The width of the seam was generally narrower than that obtained on the annealed sheet, and therefore, the electrode force was increased to 95 lb in an effort to widen the seam. Seams made at this electrode force with 40 welds per inch exhibited a marked reduction in expulsion at higher currents, and a small increase in nugget width. A current of 1250 amp produced a weld seam with overlapping nuggets having 50% penetration into each sheet and width of approximately 0.025 in.

The recommended conditions for seam welding 0.005-in. thick 3/4 hard Inconel are the same as for 0.005-in. thick annealed Inconel except that the electrode force has been increased to 95 lb and the weld current has been reduced to 1250–1300 amp. A longitudinal section of a weld made under recommended conditions is shown in Fig. 6.

TESTING OF WELDS

Weld seams were tested for pressure tightness and strength by a modified pillow test of which examples are shown in Fig. 7. Two squares, 1 1/2 in. on an edge, were cut from sheet and seam welded 1/4 in. in from each edge to form a 1-in. square centered in the sheet. Before the fourth side was welded, either dry ice (CO_2) or the material from the head of wooden matches was inserted between the sheets. After the last side was welded, internal pressure was obtained by allowing the CO_2 to vaporize or by striking the match head pillows with a hammer.

Annealed Inconel sheet, welded under recommended conditions and tested in this manner, was expanded so that considerable stretching of the sheets occurred and the internal angle between the sheets was approximately 180 deg in places. Furthermore, with the recommended welding conditions, no weld or sheet failure occurred and the pillows were pressure tight. However, weld seams with 30 welds per inch tested in this manner leaked between weld nuggets.

Pillows made from the 0.005-in. 3/4 hard sheet failed with little expansion by tearing just at the edge of the seam when match heads were used for pressurizing.

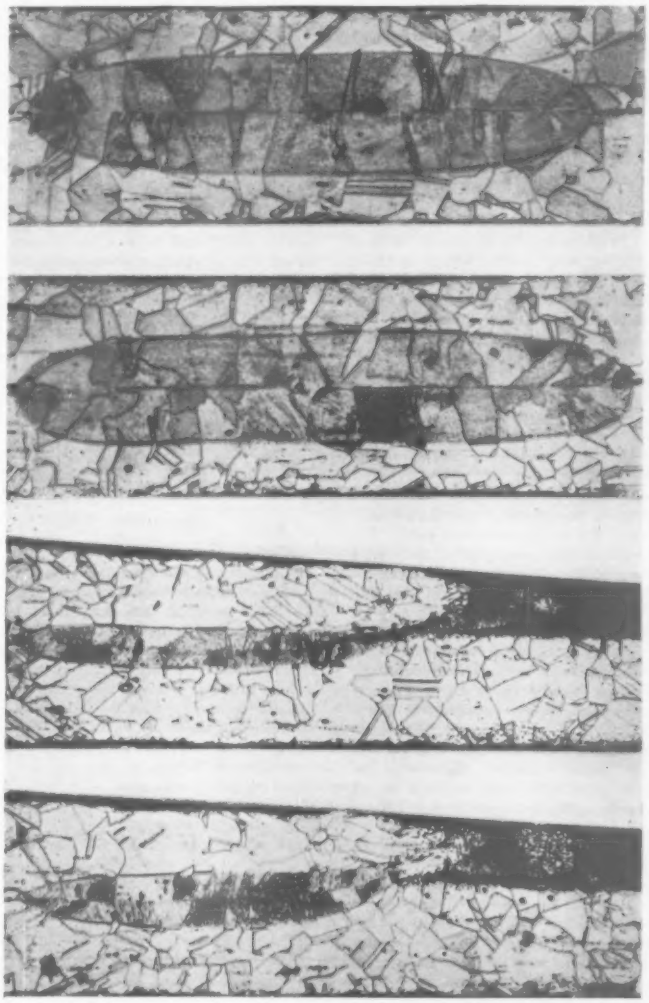


Fig. 8 Cross sections of seam welds in 0.005-in. Inconel, 75 lb electrode force, upper two 1350 amp, lower two 1150 amp edge weld, 40 welds per inch, 20 in./min. Note thin nugget and expelled metal in edge weld. 165 ×

Pillows pressurized with CO_2 were expanded considerably more before failure occurred by slight tearing at the edge of the seam. It was believed that the sulfur from the match heads caused premature failure through stress corrosion at the highly stressed region adjacent to the weld.

All the pillows could be made to fail by heating to increase the internal pressure. However, when failure occurred it was always adjacent to the weld, never through the weld itself.

It should be mentioned here that when a half-cycle weld pulse is used it is necessary that each pulse be of opposite polarity to adjacent pulses to prevent magnetizing the core of the welding transformer to saturation in one direction. If a whole number of cycles is used for the "off" time, every other half cycle pulse of current will automatically be of opposite polarity.

WELDING OF TEST SAMPLES FOR BROOKHAVEN NATIONAL LABORATORIES

Two sizes of test samples were required by Brookhaven, 12-in. square samples made by seam welding two 6- x 12-in. sheets together, and 37- x 48-in. samples made by seam welding four 12- x 37-in. sheets together. Since these welds had to serve as an effective air seal in contact with a neopreme gasket, it was necessary to make a second seam weld along the very edge of each joint. Since this required a very close work positioning control, a roll top table was constructed for the purpose of clamping and positioning the work

The required test samples were welded using the recommended welding conditions for the first seam weld of each joint. The second or edge seam weld of each joint was made using the same conditions except that the current was reduced to 1200 amp for the annealed sheet and 1050 amp for the $^3/_4$ hard sheet. A large amount of expulsion, as might be expected, occurred during the mash welding of the edge seam. This necessitated frequent redressing of the electrode wheels to obtain good results.

Cross sections from six different locations along a 1-ft weld made with the edge seam were examined microscopically. Good edge-fusion was obtained in all sections as the two typical cross sections of Fig. 8 show.

The Brookhaven National Laboratory reported that all samples sent to them formed an effective air seal between the welded sheet and a neopreme gasket.

CONCLUSIONS

1. Thin Inconel sheets, 0.005 in. thick, may be seam welded using a short "on-off" cycle provided that the movable electrode assembly of the welder has a low inertia to enable the electrode force to be maintained reasonably constant during the welding operation. A welder was designed and built to incorporate the feature of low moving head inertia and low friction.

2. Conditions were determined for welding 0.005-in. Inconel in both the annealed and $^3/_4$ hard conditions. A timing sequence of $^1/_2$ cycle "on" 4 cycles "off" on a 60-cycle supply with 40 welds per inch was arrived at for both types of sheet. A current of 1350–1425 amp and an electrode force of 75 lb was recommended for the annealed sheet and a current of 1250–1300 amp and an electrode force of 95 lb for the $^3/_4$ hard sheet.

3. Double seam welds made with the second seam at the extreme edge of the overlap were found to form an effective air seal with a $^1/_2$-in. diam neopreme gasket crossing it at right angles.

ACKNOWLEDGMENTS

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Appendix

Welding current for the seam welder shown in Figs. 1 and 2 is supplied by two 2.5-kva resistance welding transformers. The turns ratio of each transformer is adjustable in 12 steps from 110:1 to 220:1 giving a maximum secondary open circuit voltage for each transformer of 4 volts with 440 primary volts. At the highest tap setting, with the secondaries connected in series the rated secondary current is 625 amp, and with the secondaries connected in parallel, 1250 amp, both based on a 50% duty cycle, with proportionately higher current ratings at lower duty cycles.

The dead weight of the movable electrode assembly shown in Fig. 2 is approximately 25 lb with a 6-in. diam $^1/_2$-in. thick electrode in place. Additional force is applied by a screw arrangement which compresses a helical spring against the top of the movable electrode assembly. A vertical scale, graduated in tenths of an inch and mounted on the movable assembly to the front of the spring, is used to indicate the force applied by the spring. The spring used in this investigation is 2 in. mean diameter, 7 in. free height and consists of 17 turns of 0.187-in. diam Monel wire. As an example of the behavior of this spring, a force of 55 lb is supplied by compressing the spring 3.7 in. making a total electrode force of 80 lb. Greater forces can be obtained by compressing the spring until some coils touch.

The movable electrode assembly is guided by fixed ball bearing units, two front and two rear, which roll in flat grooves cut in the frame of the moving assembly. The bearings are adjustable, by means of four machine screws per bearing, to any position in the horizontal planes so that the upper wheel may be aligned with the lower wheel.

The upper wheel is mounted on a shaft made from a hollow bronze bushing to reduce weight. This shaft, which is driven only through contact with the lower wheel, is mounted in ball bearings to minimize the turning friction. The bearings are insulated from the supporting clamps by strips of heavy insulating paper.

The deep throat of 24 in. for this machine was necessary because of the size of the test specimens required by Brookhaven. This greatly reduced the electrical efficiency of the machine by increasing the power factor angle.

Turning power is supplied to the lower electrode wheel by a $^1/_6$-hp 230-v Thymotrol-controlled d-c. shunt motor. This is coupled through a double worm reduction gearbox and a roller chain to a sprocket on the rear end of the lower arm.

The reduction of the gearbox is 300 to 1 and that of the chain is 25 to 8 making an over-all reduction of 937.5 to 1. With a 6-in. diam wheel, this reduction permits varying the surface speed from 9 to 33 ipm. Faster or slower speeds can be obtained by changing the wheel diameter or by changing the sprocket ratio. The motor and gearbox are mounted on a $^1/_2$-in. steel plate which is adjustable in the vertical direction to control the slack in the chain.

Transition from Ductile to Brittle Behavior in Pressure Vessel Steels

This report has been prepared with the cooperation of an advisory panel consisting of H. C. Boardman, M. Gensamer, S. L. Hoyt, S. J. Rosenberg and Walter Samans under the sponsorship of the Materials Division of the Pressure Vessel Research Committee, Welding Research Council

by T. N. Armstrong, N. A. Kahn and Helmut Thielsch

Summary

Steel used in engineering structures is generally considered to be a ductile material. When overloaded, it usually gives warning by flowing plastically—i.e., bulging, stretching, bending or necking—before rupturing. Contrary to expectation, however, steels sometimes rupture without prior evidence of distress. Such brittle failures are accompanied by but little plastic deformation, and the energy required to propagate the fracture appears to be quite low. Under certain conditions steel may shatter like glass, but in pressure vessels this extreme behavior generally occurs only at low temperatures.

Three conditions control this tendency for steel to behave in a brittle fashion. These factors include high stress concentrations —i.e., notches, nicks, scratches, internal flaws or sharp changes in geometry—a high rate of straining and a low operating temperature. These three factors are so interrelated that a determination of the effect of any one of them gives indication of how the steel will react to intensification of either or both of the others. It so happens that the effect of lowering the testing temperature is most convenient to measure quantitatively. Therefore the transition from ductile to brittle behavior of a steel is generally expressed in terms of temperature.

The transition temperature for any steel is the temperature above which the steel behaves in a predominantly ductile manner and below which it behaves in a predominantly brittle manner. Steel with a high transition temperature is more likely to behave in a brittle manner in service. It follows that a steel with a low transition temperature is more likely to behave in a ductile manner, and therefore steels with low transition temperatures are generally preferred for service involving severe stress concentrations, impact loading, low temperatures or combinations of the three.

Many metallurgical factors, including deoxidation practice, composition, rolling practice and subsequent heat treatment, influence the transition temperature of steel which, under the worst conditions may be above 100° F or, under the best conditions, below minus 200° F.

Steels treated in accordance with most favorable deoxidation practice are those which are fully killed and treated with sufficient aluminum to insure retention of a few hundredths of a per cent residual aluminum. Such steels are generally referred to as being made in accordance with fine-grain practice.

Carbon influences the transition temperature of as-rolled or normalized steels unfavorably. Its upper limit in plain carbon steels is generally accepted as about 0.25%, and in low-alloy steels as about 0.20% or even lower. High ratios of manganese to carbon may be beneficial. Most elements other than those used for deoxidation raise the transition temperature with the notable exception of nickel, which lowers appreciably the transition temperature of carbon steel. Austenitic chromium-nickel stainless steel and some high-nickel steels show no transition at temperatures lower than minus 320° F.

Steels which have been fully annealed are in the poorest condition to resist embrittlement. Normalizing offers improvement, and frequently further benefit is derived from tempering or stress relieving after welding. Optimum properties are obtained by fully quenching and tempering to moderate strength levels, but such treatment can seldom be applied to pressure vessel steels and has not yet received full recognition in construction codes.

The presence of notches or other stress-concentration factors is of considerable importance. Serious notches in welded joints may encourage failure at loads well below those permitted by design. Any aggravated notch, just like a severe geometric shape-change, can result in a crack at relatively low loads.

Many vessels of rimmed or semikilled steels have operated satisfactorily in service for long periods although they have higher transition temperatures than fully killed steels. These steels offer cost advantages and are usually in shock-free service where failure is unlikely. However, even in the absence of shock, vessels operating under high stress should be made of steels which are tough at the lowest service temperature, such as those commercially available under ASTM Specification A-300. This is particularly important for vessels located where failure would endanger life and property.

Brittle failures rarely occur in pressure vessels. Nevertheless their prevention is of paramount importance because economics and fabrication limitations rarely favor construction of a perfect vessel. Primary emphasis should be placed upon selecting steels of suitable quality for their intended use and followed by design and fabrication practices that will hold stress-raisers to an acceptable minimum.

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INTRODUCTION

UNEXPECTED and sudden failures in pressure vessels, bridges and other structures and failures in welded steel ships have made engineers and metallurgists aware that steels which ordinarily behave in a ductile manner may, under certain conditions, exhibit highly brittle characteristics. Although few failures of this type have occurred in pressure vessels, the consequences of such sudden failures are extremely disturbing and can be tragic.

It is not unusual for engineers to ascribe the brittle fractures associated with these failures to such metallurgical causes as poor steel quality or an impairment of quality from welding operations. However, actual examination of most sudden failures of steel structures has revealed that superimposed mechanical factors were intimately associated with these brittle failures. In general, brittle failures have been found to be associated with inferior design, faulty workmanship including poor welding practice, use of a steel which is notch-sensitive under the particular operating conditions, or a combination of these influences.

Nature of Brittle Behavior

Brittle behavior in steel may result from a number of factors including (1) rapid rate of straining, (2) the presence of multidirectional stresses, or notches causing restraint such as surface defects, discontinuities, incomplete welds, underbead cracks, microcracks, sharp re-entrant corners, etc., (3) low operating temperature, or (4) a combination of these factors.

The brittle behavior of a steel is generally evidenced by sudden failure and sometimes by shattering. The initial fracture usually will propagate rapidly and, under certain conditions, the rate of propagation is practically infinite. At failure, the surface of the fracture appears bright, granular and crystalline with the cross section showing little or no evidence of necking or plastic deformation. A typical example is the notched specimen shown in Fig. 1. Such fractures are generally called cleavage fractures.

In contrast, a steel which behaves in a ductile manner generally will fail gradually, i.e., at a much slower rate. Moreover, ductile failures in pressure vessels usually are preceded by local bulging, i.e., by plastic deformation, or flow in the material because of shearing forces. Such shear fractures, as in the notched specimen shown in Fig. 2, will appear relatively dull and fibrous and show a measureable and often considerable contraction of area across the fracture section.

Evaluation of Brittle Behavior of Steels

It has been observed that the conventional static tension and cold-bend tests do not adequately differentiate between steels with regard to susceptibility to brittle behavior in a completed structure. This has created the desire for a simple test that could be used to select steels that would be considered "safe" for use under any predictable conditions. Such a test should permit selection of a particular steel for a particular type of element in the structure for use under normal and, possibly, for an occasionally unusual service condition or environment which the structure may encounter.

Unfortunately, there is no test that fulfills these requirements. This is because the currently used tests measure the mechanical properties of the steel under the particular conditions imposed by the test method, and not its behavior in an actual structure as influenced by such factors as design, workmanship, welding quality, restraints and stress distribution. Nevertheless, there are several accepted tests that are extremely useful because they permit comparison among the various types and grades of steels. Moreover, these tests, which usually require notched-bar specimens, provide some knowledge of brittle behavior and the approximate relation of such factors as thickness of the steel, deoxidation practice, sharpness of notches, heat treatment, etc., to fracture characteristics.

The determination of the temperature at which a steel may become susceptible to brittle failure under certain conditions is based on one or more of several different criteria. Those more commonly used are: (1) energy absorbed to break the specimen, (2) ductility of specimen and (3) appearance of fracture.

The transition temperature of any one grade or type of steel as determined by one type of test generally should not be compared to that of another grade of steel unless the same criterion of brittleness has been used. Under the same type of test, the transition temperatures obtained are of only qualitative value in assuring that the steel which exhibits the lower transition tempera-

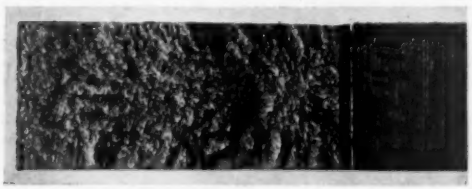

Fig. 1 Brittle fracture in mild steel—bright, granular and crystalline. Plastic deformation is absent

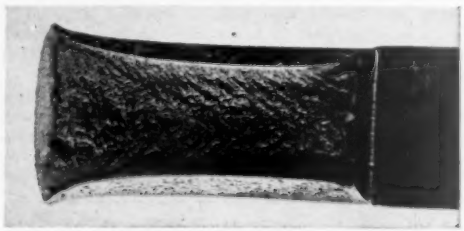

Fig. 2 Ductile fracture in mild steel—dull and fibrous. Plastic deformation is present

ture is less likely to fail in a brittle manner than the steel showing a higher transition temperature. For any particular service, however, other things being equal, the steel with the lower transition temperature should be preferred because it offers an added factor of safety, even though the limiting low service temperature of the structure may not be known precisely.

Effects of Temperature

The transition from ductile to brittle behavior of carbon and low-alloy steels is not a phenomenon only occasionally noted; it is an inherent property which can be demonstrated by a number of accepted test methods. For example, Fig. 3 illustrates schematically this transition as brought about by a decrease in the testing temperature. It should be noted that since several criteria may be employed to evaluate the transition temperature, its position with respect to the temperature scale may be expected to vary with the criterion selected.

Transition Temperature

Various tests have been developed to determine whether a steel under certain test conditions will fail definitely in a ductile or brittle manner. Each of these conditions actually shows a scatter region or a transition-temperature range (Fig. 4) within which a steel under the same set of test conditions will exhibit either ductile or brittle behavior, or both.

Usually some empirically selected point within the transition-temperature range is selected and is thereafter designated as the transition temperature for the steel tested. This temperature can be roughly defined as the temperature above which the steel under the particular test conditions will behave in a predominately ductile manner and below which the steel will exhibit a predominately brittle behavior.

For example, when the appearance of the fracture is the criterion, the transition temperature may be arbitrarily designated as the temperature at which half of the fracture surface shows a cleavage failure while the other half exhibits a shear failure. When energy absorption is the criterion, some arbitrary energy value is generally used. For example, in the Charpy test, the temperature corresponding to the 15 ft-lb value is often designated arbitrarily as the transition temperature. It must be noted that at this value the fracture may be predominately of the cleavage type. This last method is illustrated in Fig. 4. Other criteria are the temperature at which the initial appearance of cleavage (brittle) fracture is observed and the temperature at which the energy absorbed is half of the maximum energy value obtained over the testing range.

It should be recognized that there exists no one *transition temperature* for a given steel except for a particular set of conditions and one criterion of brittleness. Each particular structural section or plate thickness rolled from a given steel will exhibit a range of temperatures in which the fracture shifts from tough to brittle. This range may be varied considerably by changing the metallurgical and mechanical properties of a steel.

Effects of Notches and Notch Sensitivity

The sudden brittle failures which occur without measureable deformation are generally ascribed to notch sensitivity of steel at the operating temperatures to which it was exposed. Although not always obvious, actual notches or notch effects are present in all structures. They may consist of minute surface or subsurface cracks, visible scratches, abrupt shape changes such as sharp corners, tool marks, edges, etc., or fabrication defects.

Notch sensitivity is usually associated with an inability of the steel to deform in a plastic manner (that is to flow) underneath the notch. This resistance to flow is increased by the triaxial state of stress induced under a notch by a tensile stress. The condition is accentuated as the thickness of the plate increases. Notches also are stress raisers. The greater the sharp-

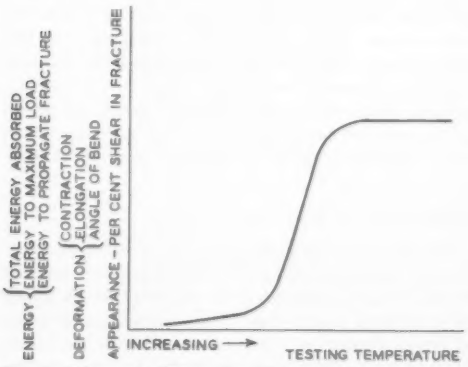

Fig. 3 Schematic illustration of transition temperature range

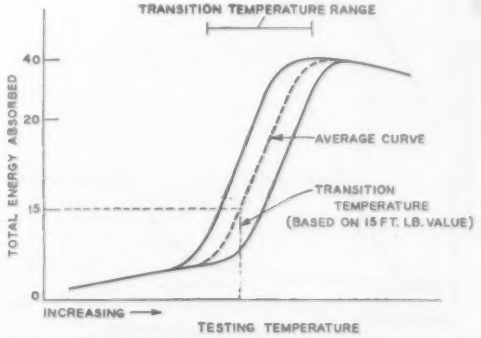

Fig. 4 Transition temperature range and transition temperature in Charpy impact test

ness of the notch, the greater will be the degree of restraint, the more severe will be the stresses as to both triaxiality and magnitude, and the higher will be the transition temperature. The effects of notches of varying severity on the brittle behavior of Charpy test specimens are illustrated in Fig. 5. This is the basis of the general concept that the transition-temperature range or the arbitrarily selected transition temperature will increase with the severity of the notch. In other words, a steel which contains extremely severe notches will fail in a brittle manner at higher ambient temperatures than if less severe notches were present.

It should also be noted that in instances where service conditions impose a triaxial state of stress, as is true of internally loaded pressure vessels, brittle behavior may be encountered even in the absence of notches.

TEST METHODS

Various "small scale" tests have been developed to evaluate the notch-sensitivity of steel. These tests may be divided roughly into three categories consisting of single-blow notched-bar impact tests, slow-bend notch tests and notched tensile tests. The latter include the symmetrically loaded type of specimen such as the edge-notched plate test and the asymmetrically loaded type of specimen such as the Navy Tear Test.

"Small scale" notch toughness tests are generally made for one of three primary purposes: (1) to examine and correlate the metallurgical characteristics of various types of steels; (2) to inspect the steel (approve or reject) in accordance with specification and code requirements and (3) to indicate in so far as possible the service behavior of a particular steel in a finished structure.

The examination and correlation of metallurgical characteristics is of interest primarily to the metallurgists who, by means of these tests, can evaluate the effects of steel-making and rolling practices, composition, heat treatment, etc., on the mechanical properties of steel.

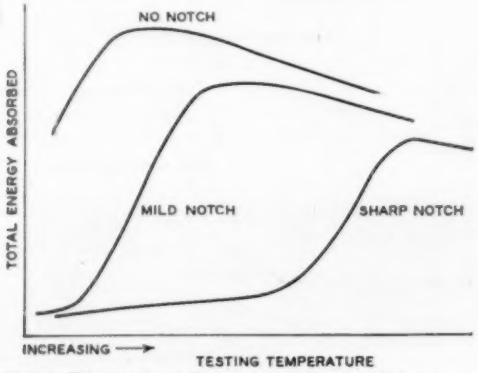

Fig. 5 Effects of notch severity on the transition temperature

The "acceptance" tests made in accordance with requirements on construction codes and materials specifications, and the tests made to obtain an indication of service behavior are of major interest to the engineer, and are of course also useful to the metallurgist, as they guide him in his efforts to obtain steel of the desired properties.

Determination of the effects of metallurgical variables on the test properties of steels is relatively simple but to interpret the effect of these variables in terms of probable service behavior is extremely difficult. One reason for this difficulty is that, in many respects, the steel in a relatively rigid structure does not behave in the same manner as it does in small-scale laboratory specimens. Moreover, in assembled structures, certain mechanical shape and assembly factors and adverse effects of fabrication procedures and workmanship may come into play. Consequently, the results obtained with the conventional notched-bar testing procedures on small specimens are not necessarily the same that would be obtained from tests of full scale structures of the same steel.

Some large-scale plate tests, such as the "hatch-corner" tests and direct explosion tests have been suggested for evaluating the effects of welding and other fabricating processes. The initial results of direct explosion tests indicate significant differences in the performance of steels which have been welded by different procedures. Ultimately these tests may prove to be useful for determining the proper welding procedure to obtain low transition temperatures in weldments.

Code-Test Requirements

For carbon and low-alloy steels for use below −20° F, the 1950 edition of the Unfired Pressure Vessel Code, Section VIII, of the ASME Boiler Construction Code requires that three Charpy keyhole specimens exhibit an average impact value of 15 ft-lb at the lowest operating temperature, with only one of the specimens permitted to show a minimum of 10 ft-lb. The V-notch Charpy and the Izod specimens are not recognized by the 1950 Unfired Pressure Vessel Code, although the 1949 edition permitted the Izod specimen. ASTM Specification A300–51T for steel plates for pressure vessels for service at low temperatures also requires an average of 15 ft-lb for three Charpy keyhole specimens at the specified test temperature, with only one specimen permitted to have a minimum value of 10 ft-lb.

Significance of Test Data

Mechanical-property requirements of standard specifications for steel plates supply only limited information to the designer, although such requirements are useful in purchasing and in classifying materials on the basis of tensile properties. One reason tensile test data are of limited application in design is that the tension test is uniaxial, whereas the hazard of brittle failure

is due to the existence of multiaxial stresses and stress concentrations. Thus, the static tensile strength, yield strength and ductility of the unnotched tensile bars at ambient temperatures represent a relative quality factor rather than a value that applies to design. This is substantiated by the fact that certain special alloy steels, which in the conventional room-temperature tensile test have elongation values of slightly under 5%, have given satisfactory service in many applications. However, these special steels had been processed to develop transition temperatures considerably lower than that of mild steel having conventional tensile ductility values above 20%, and in the applications involved, steels of higher transition temperatures would not have performed satisfactorily no matter how high their tensile ductility at room temperature.

There is no intent to discount the need for ductility in the steel for satisfactory performance in pressure vessels, but ductility at room temperature as determined in the static tensile test does not necessarily indicate that the steel will behave in a ductile manner under different conditions of stressing. For instance, large cross-sectional areas and undesirable design features may cause mechanical restraint. As mechanical restraint opposes plastic deformation, the steel will fail in a brittle manner if restraint is sufficiently severe and if the temperature is sufficiently low. The major difficulty is that there is no accepted method of correlating ductility and toughness with other mechanical properties obtained from standard tensile or notched-bar tests that can be applied to assure the most efficient use of a steel in a pressure vessel.

Ductility and Fracture Transition

Test results obtained with many types of specimens usually will show two transition temperatures instead of one. This is shown schematically by the solid curve in Fig .6. The two transition temperatures are identified as fracture transition and ductility transition. The drop in energy at T_E (the fracture transition) is generally associated with the change in fracture appearance over the fractured surface which occurs in this temperature region. The drop at T_N (the ductility transition) is accompanied often by a change in fracture appearance of a small zone at the base of the notch.

The temperature at which the ductility transition occurs is very much dependent upon notch geometry and the influence of plastic straining prior to failure. As the notch is made sharper and deeper, the strain is more localized and the degree of triaxiality of the state of stress is greater. This leads to higher ductility-transition temperatures.

The fracture-transition temperature range, on the other hand, is relatively less sensitive to notch geometry as specimens with different size notches may show widely different ductility transitions without exhibiting similar differences in the fracture-transition temperatures. As an example, in Fig. 7 are shown schematically the transition curves for (*A*) large, centrally notched, wide-plate specimens and for (*B*) small notched specimens.

Both transition-temperature ranges have a bearing on the behavior of the steel. Whereas the ductility transition (T_N) is associated with the initiation of a crack, the fracture transition (T_E) is associated with its propagation.

FACTORS DETERMINING TRANSITION TEMPERATURES

The factors which influence the transition-temperature range of a steel may be separated into (*A*) Metallurgical factors and (*B*) Mechanical Factors. The metallurgical factors are characteristic of the steel itself, whereas the mechanical factors depend upon the service or testing environments as well as many effects produced by fabricating procedures. An analysis and understanding of the various factors is often highly important, particularly when it is desirable to make the most efficient use of a particular steel.

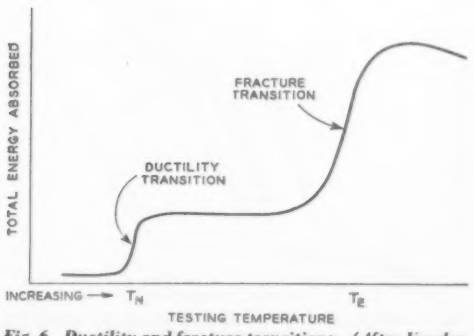

Fig. 6 Ductility and fracture transitions. (After Vanderbeck and Gensamer[4])

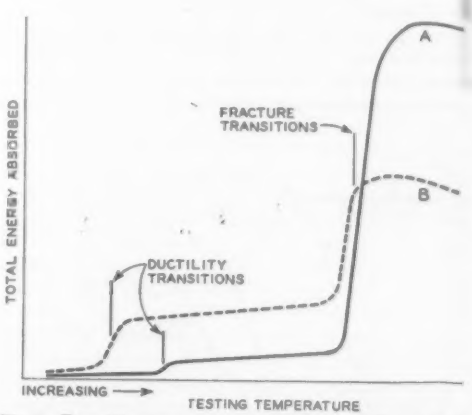

Fig. 7 Transition temperatures of large, centrally notched, wide plate specimens (Curve A) and of small notched specimens (Curve B). (After Vanderbeck and Gensamer[4])

(A) *Metallurgical Factors*

Effects of Composition. Carbon and nitrogen are believed by many investigators to be the most important elements which raise the transition temperature of steel in the as-rolled or normalized condition. Oxygen and phosphorus, in quantities greater than normally tolerated, and silicon in percentages greater than required for deoxidation, also may raise the transition temperature. In fact, most additions usually made to steel raise the transition temperature. The additions that will lower the transition temperature are nickel and, under certain conditions, manganese. Nickel is frequently added to low-carbon steel when a transition temperature below that obtainable with carbon steel is desired. Aluminum, in the range of quantities used for deoxidation, is very potent in lowering the transition temperature and is used in practically all steels that are made specifically for low-temperature service.

Commercial mild steels, even those within the same grade, may exhibit considerable differences in their notch-sensitive characteristics. These differences, which are not predictable from the conventional chemical analyses, may be attributed to various factors such as steel-making practice, deoxidation, grain size, finishing temperature, thickness of section, heat treatment and others.

In the fully quenched and tempered condition, composition, other than high-carbon content, does not appear to be much of a factor provided the steels harden fully on quenching. Exceptions are steels that are susceptible to temper embrittlement. Effect of composition on transition temperature of steel is still the subject of considerable study. There is some indication that nitrogen present as aluminum nitride may be beneficial, but detrimental if present as other nitrides.

Homogeneity. It is generally recognized that the concentration of carbon, alloying elements and impurities varies throughout the ingot and, consequently, throughout the finished steel plate. These variations in composition affect the conventional mechanical properties as well as the notch characteristics and the transition temperature. For example, in one series of tests the ductility in the tension test increased whereas the strength decreased from the top to the bottom and from the center to the edge of the ingot in ASTM A201 (aluminum-killed) and A285 (rimmed) steels. In the Charpy-keyhole notched-bar test, the toughness increased and the transition-temperature decreased from the top to the bottom of an ingot. These effects all were consistent with chemical variations.

Some plate steels show marked directional properties such as higher values for ductility and notched-bar impact when tests are made on specimens taken parallel to the direction of rolling as compared to specimens taken transverse to the direction of rolling. Directional properties may be minimized by cross rolling and by certain heating procedures prior to rolling.

Effects of Grain Size. The smaller the ferrite grain size, the lower generally will be the transition temperature. Thus, the lower the final rolling temperature of the steel and the higher the cooling rate, the smaller will be the grain size and the lower will be the transition temperature unless the final rolling temperature is so low that the steel is to some degree cold rolled.

Aluminum additions during final deoxidation are useful in providing fine grain size in normalized material. A normalizing treatment is particularly effective if the plate was finished at a high rolling temperature.

Effects of Straining. Cold deformation or straining generally raises the transition temperature of a steel, Fig. 8, especially the ductility transition. The fracture transition is not affected until the ductility transition has been raised to the level of the fracture transition.

Effects of Straining and Aging. The transition temperature of a steel, which is susceptible to strain aging, is raised to a higher temperature after straining and aging than after straining alone. This is illustrated in Fig. 9 which shows results which may be expected in a rimmed steel

Effects of Heat Treatment. Ordinarily, structural mild steel is used in the as-rolled state. Hot rolling is generally performed between 2200 and 1600° F and is followed by air cooling. Under these conditions these steels can be compared to normalized steels, although it should be recognized that the temperature of finish rolling is an important factor.

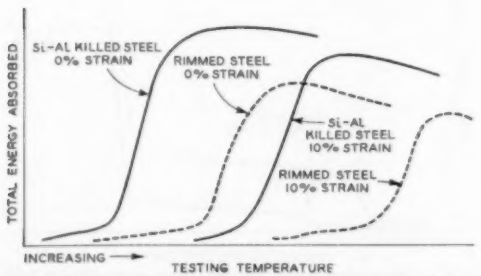

Fig. 8 Effects of straining on the transition temperatures of Si-Al killed and rimmed steels. (After 23, 27, 90, 91)

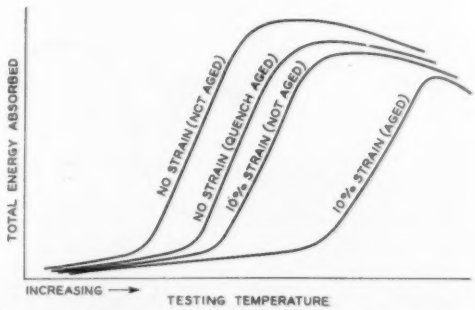

Fig. 9 Effects of straining and aging on the transition temperature of a rimmed steel. (After 9, 23, 27, 58, 89, 90, 91)

As large sections are usually finished at higher temperatures and cool more slowly than the light sections, they exhibit higher transition temperatures. This is at least in part due to the coarser grain size, and to the coarseness and distribution of pearlite.

The form and distribution of the carbide have a profound influence on the transition temperature of steel. In general, lowest transition temperatures are obtained with liquid quenching and tempering treatments. Normalizing or normalizing and tempering is the second most effective treatment. Conventional annealing cycles consisting of heating to above the critical range followed by slow cooling to ambient temperatures result in high transition temperatures, especially if the annealing temperatures is so high as to cause grain coarsening, and such treatments are not recommended for pressure vessels. Normalizing and tempering or a stress-relief heat treatment at 1100° F or above, but not higher than 1250 to 1300° F, are the preferred treatments. The range 1350 to 1450° F sometimes raises transition temperature, and should be avoided; likewise, low-temperature stress-relief heat treatments (below 900° F) are to be avoided in some instances, as they raise the transition temperatures.

Effects on Strained Plates. Normalizing at 1600° F is an effective heat treatment for restoring the ductility and transition temperature of cold-worked plates to their levels in the unstrained plates. Stress relieving at 1100 to 1150° F may result in some improvement but is not as effective as normalizing. Heating strained steel plates to 800° F may reduce ductility and raise the transition temperature.

(*B*) *Mechanical Factors*

Various mechanical factors may also exert considerable influence on the transition temperature of a steel. Most important are the stress system, section size, design, workmanship, welding practice and others.

Effect of the Stress System. Multiaxial tensile stresses raise the transition temperature. This is particularly true at the base of a notch or crack where multiaxial tensile stresses of considerable magnitude may develop.

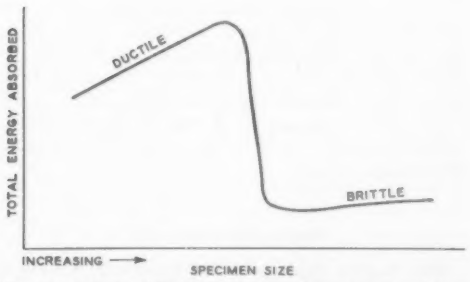

Fig. 10 Relationship between size of specimen and type of fracture. (After Hoggart[3])

Effects of Section Size. If the section size is increased without other changes in geometry, the transition temperature will also be increased. As is illustrated in Fig. 10, the amount of energy absorbed rises as the section size is first increased and the fracture remains ductile, but beyond a certain critical size there is a sharp drop in energy accompanied by a change to brittle fracture. Further increase in size results in a very slight increase in energy absorption, but the fracture remains brittle. These results are partially due to the greater restraint of the wider specimens which increases the severity of the triaxial stresses.

Effects of Design. Design based upon conventional tensile test data gives no assurance that a vessel will not fail in a brittle manner. Nor can such assurance be obtained by simply increasing the section size with the intent of increasing the "factor of safety" as, in the presence of notches, increase in section size will most likely increase restraint and may even lead to failure at lower applied loads.

The designer must take into account the conditions which promote notch sensitivity and attempt to control these conditions so that the ductility transition temperature of the vessel, under the particular conditions of design and service, will be below the temperature at which it operates. This may be accomplished by selecting the proper steel, by using generous radii, by limiting the extent of surface defects and by controlling welding and other fabrication procedures. When it is necessary to incorporate undesirable design features or when economic considerations restrict selection of the steel, the adverse factors may be at least partly offset by using a low design stress and, where possible, avoiding shock conditions in service. It also can be assumed that if the vessel fails under these conditions it will fail in a brittle manner. The hazards associated with sudden failure of such a vessel will dictate whether it should be used. If these hazards are great enough, the fracture transition temperature should be below the minimum service temperature.

Effect of Workmanship, Welding. Workmanship represents an intangible but highly important factor, the effect of which is difficult to evaluate in the completed structure. Inspection methods utilizing sectioning or radiography, supplemented by application of magnetic powder or fluorescent penetrants at critical locations, have generally been most helpful in judging and controlling the quality of workmanship. These inspection procedures, when judiciously applied, also have the psychological effect of influencing the welder to improve his workmanship and thus reduce the probability of incorporating notches into the structure.

It is even more difficult for the engineer to evaluate the properties of weld deposits than to evaluate the mechanical properties of wrought, unwelded plates. This is so primarily because the conventional testing procedures have not been correlated with the service behavior of the material after it has been welded. For example, one electrode may be preferred over another because the weld metal produced from it develops

higher tensile strength. However, it might well be that an incipient surface crack will propagate readily in the weld deposit made from the one electrode but not in the deposit from the other, because the latter has ability to adjust itself plastically at the service temperature.

In welded structures, it is advisable to keep the width of the heat-affected zone as narrow as possible by means of rapid rates of electrode travel. When the layer thickness of the weld metal is held constant, faster rates of electrode travel reduce the width of the heat-affected zone. Apparently the effect of the heat from the retreating arc is minimized, thus reducing the width of the heat-affected zone. This is desirable because transition temperatures tend to rise as the heat-affected zone becomes wider. The effects of width of the heat-affected zone on the transition temperature are illustrated in Fig. 11.

Welded structures in the as-welded state always contain residual welding stresses, which in certain sections may be as high as the yield strength of the steels. Under certain conditions, these residual stresses may not be particularly harmful. This is confirmed by the fact that many structures and vessels have given highly satisfactory service without having received stress-relieving treatments subsequent to welding operations. Moreover, when failures have occurred, it was generally found that they were brought on by causes other than residual stresses alone.

When residual stresses are believed to be a factor in the service life of a vessel, a stress-relief heat treatment should be applied. In some instances, stress relieving may raise the transition temperature.

It has been demonstrated by certain restraint tests, such as the circular-groove tests, that for specific preheat and interpass temperatures the degree of restraint during the cooling cycle affects the transition temperature of weld deposits. When controlling preheat and interpass temperatures at 70 to 100° F, the transition temperature of low-alloy steel weld metal deposits has been raised from −90 to +10° F by increase in restraint. Where the degree of restraint is held constant, increasing the preheat and interpass temperatures effectively lowers the transition temperature of the weld deposit.

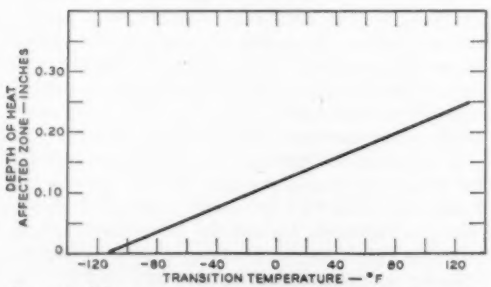

Fig. 11 Effect of depth of heat-affected zone on the transition temperature of a welded rimmed steel (Jackson[29]). (Composition: 0.16% C, 0.45% Mn, 0.01% Si)

Welding at temperatures below zero degree F is not permitted by existing AWS codes. Such practice will produce weld deposits having reduced ductility and impact toughness. The drop in ductility becomes pronounced at welding temperatures below −50° F. Results of impact tests showed that specimens welded at −50° F exhibited a toughness 15 or 20% lower than specimens welded at ordinary atmospheric temperatures (75° F).

Extensive investigations of the last few years indicate that, due to a combination of hydrogen and straining, ordinary electrodes of the E6010 type produce microcracks as the weld cools from 500° F to ambient temperature. Preheating, or the use of E7015 or E7016 type electrodes, circumvents this difficulty.

FIELDS FOR FURTHER STUDY

Although a very large number of studies have been conducted during the last decade on the subject of transition temperature, there are still a great many gaps in technical knowledge. For example, there still is no generally accepted method for correlating the behavior of small-scale test specimens with the service behavior of large sections.

The effects of heat treatment, composition and structure need further study. Because pressure vessels are usually subject to triaxial stresses and may be subjected to fluctuating pressures and occasionally to shock or impact loads at low temperatures, the use and further improvement of materials and fabricating methods that produce or enhance notch toughness are highly desirable.

More information is desired on the effects of welding and the effect of preheat and postheat treatments. Also, little, is known about microfissuring and notch toughness of weld metal deposited under conditions of high restraint.

There is a lack of information on the effect of fabricating processes other than welding. Additional studies on the degree of restraint induced by thickness of the section might prove fruitful.

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Since the above discussion is intended to serve primarily as an interpretive engineering statement, detailed research results as well as theoretical hypotheses have been omitted. Moreover, the

great many different tests which have been developed by various investigations, as well as their merits and disadvantages, have not been discussed since a discussion of this kind would constitute a monograph in itself. Such information can be found in the articles listed in the bibliography. General discussions on notch sensitivity can be found in references 3, 6, 7, 15, 19, 28, 45, 64, 73; the major tests are discussed in Kinzel Bend Test 51, 64, 65; Lehigh Bend Test 2, 7, 9, 14, 21, 23, 36, 51, 71, 72, 83; Pennsylvania State Test 9, 37, 38; Miscellaneous Notched-Bend Tests 25; Navy or Kahn Tear Test 9, 11, 22, 30, 40; Bagsar Cleavage Tear Test 27, 59, 60; Schnadt Test 18, 20, 74, 76; Keyhole-Type Impact Tests 13, 27, 35, 77, 80, 86; V-Notch Type Impact Tests 10, 23, 25, 27, 31, 35, 41, 43, 44, 62; Notched Tension Impact Tests 39, 46, 52; Notched Tension Tests 24, 49, 50, 54, 56, 57, 63, 70; Explosion Tests 48, 79. Moreover, the following references give information on the effects of heat treatment 34, 72; composition 21, 54, 58, 65, 67, 84; structure 57, 72; aging 21, 34, 92; strain aging 42, 69, 75, 78, 81, 82, 91; fatigue 47, 61; welding and pre- and postheat treatments 2, 21, 31, 36, 44, 46, 48, 51, 55, 64, 66, 67, 68, 86, 89, 90, 91; alloy steels 53, 85; low-alloy high strength steels 25.

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WELDING RESEARCH COUNCIL BULLETINS

The Welding Research Council has inaugurated a series of Bulletins to include reports for which space cannot be provided in the regular Welding Research Supplement. These Bulletins are furnished to the contributors and research workers of the Council and placed on sale at a nominal charge through the AMERICAN WELDING SOCIETY. A list of the Bulletins published to date and their prices are:

No. 1. *Steel Compositions and Specifications*, by Charles M. Parker, March 1949. Price: Fifty cents.

No. 2. *The Nature of the Arc*, by J. D. Cobine, April 1949. Price: Fifty cents.

No. 3. *Burn-Off Characteristics of Steel Welding Electrodes*, by D. C. Martin, P. J. Rieppel and C. B. Voldrich, May 1949. Price: Fifty cents.

No. 4. *Testing Pressure Vessels*, by F. G. Tatnall, and *Effect of Welding on Pressure Vessel Steels*, by A. F. Scotchbrook, L. Eriv, R. D. Stout and B. G. Johnston, February 1950. Price: Fifty cents.

No. 5. *How Plastic Deformation Influences Design and Forming of Metal Parts*, by John R. Low, Jr., and *Brittle Fracture in Mild Steel*, by J. S. Hoggart, May 1950. Price: One dollar.

No. 6. *Stress Corrosion Cracking of Stainless Steels*, by Helmer Nathorst. Part I—Practical Experiences; Part II—An Investigation of the Suitability of the U-bend Specimen, October 1950. Price: One dollar.

No. 7. *Instrumentation for the Evaluation of the Stability of the Welding Arc*, by L. P. Winsor, L. McDonald Schetky and R. A. Wyant, November 1950. Price: One dollar.

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No. 10. *Thermal Fatigue and Thermal Shock*, by Helmut Thielsch, April 1952. Price: One dollar.

No. 11. *Investigations of Effect of Fabrication Operations Upon Pressure Vessel Steels*, by S. S. Tör and Robert D. Stout, May 1952. Price: One dollar.

Porosity in Mild Steel Weld Metal

A review of the literature on each of the factors effecting porosity in mild-steel weld metal

by Donald Warren and R. D. Stout

INTRODUCTION

METALS in the process of being fusion welded are susceptible to the formation of porosity. This porosity is related to the release and the subsequent entrapment of gases during the solidification of the weld metal. The evolution of gases during welding may occur by virtue of a reduced solubility with decreasing temperature or by chemical reactions. Whether such an evolution results in the formation of voids depends upon the nature and quantity of the gases released and the conditions under which the fused metal solidifies.

There have been several reviews written on the subject of porosity in weld metal in the past few years. The first of these by Herres[1] was included in a general discussion of the effects of hydrogen on the arc welding of steel. Following this, Fast in Holland published a series of papers[2-4] dealing in whole or in part with porosity in weld metal. The most recent reviewed by Hatherly[5] dealt with porosity as part of a discussion on the physical metallurgy of gas-metal reactions. Outside of these reviews, there are only brief references to the nature and causes of porosity scattered throughout the welding literature.

In this review, those processes leading to the evolution of gases during welding will be covered first and will be followed by a discussion of those factors that determine whether such evolution will result in porosity.

GAS SOLUBILITY: ITS EFFECT ON POROSITY

When a metal is melted in the presence of a gas, it may absorb considerable quantities of gases in a very short time. The quantity of gas dissolved is an exponential function of the temperature of the molten metal, increasing with increasing temperature, and for a diatomic gas is proportional to the square root of its partial pressure above the melt. The dissolution of gases is seldom desirable because solution is a completely reversible process. A gas absorbed during melting is generally released or desorbed during cooling because of the rapidly decreasing solubility coupled with a very sharp solubility decrease at the melting point. The excess gas can diffuse through the liquid to the surface where it recombines and is evolved, or it can form gas bubbles in the liquid and rise to the surface in this form. Whether or not gas cavities are formed in the metal will depend upon the rates of these two processes and upon the rate of solidification. This has been illustrated nicely by Fast[4] who melted and rapidly cooled four lumps of iron, one each in vacuum, hydrogen, nitrogen and argon. Those melted in vacuum and argon contained no cavities whereas those melted in hydrogen and nitrogen showed evidence of strong gas formation. When the same experiment was repeated using a slow cooling rate instead of a rapid one, the lump melted in hydrogen showed only a few cavities because most of the dissolved hydrogen was able to escape through diffusion. However, the lump melted in nitrogen still was extremely porous because the nitrogen diffused too slowly for the decreased cooling rate to have had any effect.

In welding, cooling rates are generally high and bubbles of gas coming out of solution may be entrapped by growing crystals in the melt and produce globular voids. Where the cooling rate is sufficiently high, the gas may be retained in supersaturated solid solution.

Of the gases commonly encountered in welding processes, only hydrogen, nitrogen and oxygen are soluble in molten steel to any appreciable extent. The inert gases helium and argon, as well as carbon monoxide and carbon dioxide, are virtually insoluble. All three of the soluble gases are absorbed atomically; and if present in the molecular or combined form, they must first be dissociated by the heat of welding, the electric arc or by chemical reaction.

Hydrogen

Molten steel weld metal can and does absorb well over 0.003% H_2[1, 6] by weight at 1600° C, the exact amount depending upon the partial pressure. In comparison, the solid solubility of H_2 in steel at the melting point is 0.0012%.[7] Using vacuum fusion techniques, Reeve[8] and others[9] have measured quantities of H_2 in weld metal varying from 0.0004 to 0.0016%.

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Nitrogen

Up to 0.04% N_2[10] may be present in liquid steel at equilibrium conditions whereas the solid solubility of N_2 in steel at 890° C is only 0.002%.[2] Nitrogen contents up to 0.15% in weld metal deposited with bare electrodes and up to 0.06% for weld metal laid with coated electrodes have been reported.[9, 11, 12]

Oxygen

The WELDING HANDBOOK[10] lists a solubility for O_2 in steel of about 0.2% above the melting point and about 0.1% below the melting point. Fast[2] has given a maximum solubility of 1.2% for O_2 in iron at its boiling point (2750° K). He also reported experiments of Losana where O_2 contents of 0.14–0.95% were obtained in weld metal deposited with bare electrodes. For coated electrode deposited weld metal, O_2 contents up to 0.14% have been measured.[9]

Formation of Porosity by Soluble Gases

There is disagreement among various investigators as to whether hydrogen, in itself, is capable of causing porosity. Some[13] feel that hydrogen alone cannot form bubbles in steel although it can produce microfissures by precipitation at dendritic interstices during solidification. Mallett[7] states that hydrogen may be the cause of porosity in welds made with cellulose-coated electrodes where hydrogen is dissolved in excess of its solid solubility, but that the amounts of hydrogen present in weld deposits made with mineral-coated electrodes do not appear capable of producing porosity. Doan and Bounds[14] have shown that welds made in hydrogen with pure iron electrodes were only mere shells of beads and those deposited with steel electrodes were also extremely porous. Both types of welds continued to bubble and blow for some seconds after deposition. In the obvious cases of porosity where welding has been done on surfaces covered with moisture, paint or oil, Andrews[15] believes that hydrogen is the probable source of difficulty. According to Frumin, *et al.*[16], the main cause of pore formation in the submerged arc process and in the welding of rusty metal is the solution and subsequent evolution of hydrogen. He also suggests that nitrogen stimulates pore formation in the same way.

Usually, however, excessive nitrogen is not encountered in welding except where bare or stainless steel electrodes are used. That nitrogen is a potent factor in the formation of cavities in welds laid with bare wire electrodes has been demonstrated by Fast.[2] He laid welds in air using both carbon-free plates and electrodes and obtained beads which were just as porous as welds laid using commercial wire and plate containing about 0.1% carbon.

A different method[1] by which hydrogen and nitrogen can contribute to pore formation is by the diffusion of these gases into bubbles already formed by the carbon monoxide or water vapor reactions (to be discussed later). Because these bubbles will have a zero partial pressure for H_2 and N_2, these two gases will diffuse into them rapidly in an attempt to establish equilibrium.

Not much is mentioned in the literature concerning the effect of changes in the solubility of oxygen on the formation of porosity, but this gas plays an important role in the carbon-oxygen and hydrogen-oxygen reactions to be discussed next.

GAS REACTIONS IN WELD METAL

Gas reactions during fusion welding are important because the products of these reactions may produce voids if they are entrapped in the solidifying weld metal. Among those reactions which are capable of initiating porosity in steel weld metal are the reaction of carbon or hydrogen with oxygen and the reaction of hydrogen with sulfur, selenium or carbon. Of these, the former are the more common and probably the more important.

Water Vapor Reaction

The hydrogen-oxygen or water vapor reaction is given below:

$$FeO + 2H \leftrightarrows Fe + H_2O \qquad (1)$$

If hydrogen is present in the weld metal, then this reaction will continue until either the hydrogen or oxygen content has been reduced to a value approaching equilibrium. Some investigators[17] have attributed the porosity commonly observed in welds made with dead-soft or oxidized electrodes to the reaction between hydrogen from the electrode coating and iron oxide inclusions in the weld metal.

Carbon-Oxygen Reaction

If the oxygen content of the molten weld metal is sufficiently high when the water vapor reaction has stopped, then reaction of the oxygen with silicon, manganese or carbon will occur. In general, the silicon content must first be depleted before the oxygen is free to combine with carbon according to the reaction below:

$$FeO + C \leftrightarrows Fe + CO \qquad (2)$$

Once begun, the carbon-oxygen reaction continues until the concentration of either element reaches a very low value or until solidification is completed. The reaction may proceed even when the over-all or average concentrations of iron oxide and carbon in the weld metal are actually below the equilibrium values. This is because both iron oxide and carbon are rejected during solidification of the melt to produce local concentrations sufficient for the formation of carbon monoxide.[18] In line with this view are the experi-

ments of Doan and Schulte[19] who laid sound welds on pure iron plates with purified carbonyl iron wire (0.002% O and 0.009% C) in 99.3% argon. If there was a slight decrease in argon purity or if the wire was used without purification (0.01% O and 0.016% C), then porous welds were obtained. These results indicate that with carbon contents of 0.009% or higher and in the absence of other deoxidizing elements, porosity may be caused by the presence of only slight amounts of oxygen in either the electrode or the atmosphere.

That the gases which produce porosity may be derived solely from reactions within the steel welding rod itself was shown by Doan and Bounds[14] who observed globules on the ends of rimmed steel electrodes (0.05% C and 0.012% O) used to lay welds in pure argon. When sectioned these globules proved to be the result of large cavities. The contribution of the carbon-oxygen reaction to the formation of porosity was noted as early as 1931 by Jenks[20] who attributed the decarburization adjacent to gas cavities, as well as the absence of oxides in these cavities, to the formation of carbon monoxide. The difficulties caused by the carbon-oxygen reaction still exist even with today's improved methods of welding. This is borne out by Gibson[21] who encountered gross porosity in the welding of low-carbon rimmed steel by the tungsten electrode, inert-gas shielded arc process. The formation of voids by the water-vapor and carbon monoxide reactions will be discussed further under the effect of electrode coatings.

Hydrogen Reaction with Sulfur and Selenium

When steels which contain sulfur and selenium are welded where large amounts of hydrogen are present in the arc, porous weld deposits are obtained. This porosity is generally believed to be due to the following reactions:

$$S + 2H \leftrightarrows H_2S \qquad (3)$$

$$Se + 2H \leftrightarrows H_2Se \qquad (4)$$

Sulfur can, of course, also react with oxygen to form sulfur dioxide.

Porosity was observed by Herres[1] in the repair welding of a steel casting containing selenium when high-hydrogen (cellulose-coated) electrodes were used while sound welds were obtained with low-hydrogen (mineral base) electrodes. Numerous other investigators[4, 22–25] have noted the surface pitting or porosity that occurs when high-sulfur free-machining steels are welded with ordinary electrodes. It has been pointed out that a segregated steel in which the sulfur content is high only near the center of the plate may also cause porous welds.[26] Sound welds on high-sulfur steels have been produced by using electrodes with mineral or lime-base coatings in place of cellulose coatings.[1, 23, 24] Another method is to use electrodes having basic and strongly oxidizing characteristics in order to desulfurize the weld metal.[22]

Fast[4] states that sulfur can also cause porosity by poisoning the liquid-solid interface in the weld thereby delaying gas evolution (from the carbon-oxygen reaction) until late in the solidification process where it is more apt to produce voids. In support of this hypothesis, he laid welds with cellulose-coated electrodes on carbon-free plate containing 0.25% sulfur and obtained an appreciable reduction in surface porosity when carbon-free core rods were used in place of ordinary core rods.

Methane Reaction

Very little is known about the reaction of hydrogen with carbon to form methane:

$$C + 4H \leftrightarrows CH_4 \qquad (5)$$

Zapffe and Sims[27] claim that the decarburization noted adjacent to gas cavities is due to the presence of hydrogen in these voids. Hatherly[6] states that methane may be formed in certain extreme cases where the hydrogen content of the weld metal is high and the oxygen content low.

Decomposition Reactions

The chemical decomposition of fluxes or components of electrode coatings to produce a gas may lead to porosity when such materials are accidently occluded in the molten weld metal, e.g., limestone particles from mineral-type electrode coatings.[28]

Sims[29] feels that where nitrogen is present it is a potent factor in the porosity of freezing steel through the formation of gas by decomposition of newly precipitated, unstable iron nitrides in the solidification zone.

FACTORS CONTROLLING THE FORMATION OF POROSITY IN WELDS

Welding Atmosphere

Among the gases which come into contact with the melt during the various welding processes are H_2, O_2, N_2, CO, CO_2, He, A and H_2O. The gases produced in electric arc welding with coated electrodes are the four components of the water-gas reaction:

$$CO + H_2O \leftrightarrows CO_2 + H_2 \qquad (6)$$

While the total and the relative quantities of gases have been found to vary with the type of electrode coating used,[11, 29] the amount of CO and H_2 is generally never less than 75% of the total gases formed.

In gas welding CO, H_2, CO_2 and H_2O are present in the welding flame; the first two in the inner cone and the last two in the outer cone. In the atomic hydrogen and the various inert-gas shielded processes, gases other than the shielding gas are generally excluded from the arc. When bare electrodes are used or when ineffective shielding[30] is present in any of the other

welding processes, there is opportunity for the air (N_2, O_2 and H_2O) to contact the weld metal and cause porosity.

Some general observations have already been cited on the formation of voids in weld metal by certain of the gases mentioned above (H_2, N_2, O_2 and H_2O). In addition, Doan and co-workers[14, 19, 31, 32] have made an extensive study of the effect of various atmospheres in the welding of steel. However, many of their observations concerning porosity are not pertinent to the particular welding atmosphere because of their use of a rimmed steel electrode which was capable in itself of producing gross porosity. Mallett and Rieppel[29] have studied the effect of various welding atmospheres using a hollow steel electrode by which the synthetic atmosphere was introduced into the arc. They found that a 50% CO-50% CO_2 mixture produced welds free from porosity.

Welding Electrode Core Wire

Voldrich, Martin and Rieppel[25] made a number of bare wire welds using rimmed, capped and killed steel electrodes and found that all of the welds were extremely porous with no trend or relation between the porosity and the type of wire used. In the same study a series of commercially acceptable welds were made with coated electrodes using rimmed, capped and killed steel core wires; in this case, there was insufficient porosity to establish any relation between type of core wire and the number of voids. The most important core wire variable was the sulfur content which, when greater than 0.040%, led to violent boiling in the weld pool and sometimes to surface pitting or porosity.

In contrast to electric arc welding with coated electrodes where rimmed steels are generally used for core rods to obtain efficient metal transfer, the inert-gas shielded arc processes require the use of killed wire electrodes or filler metal in order to avoid the formation of porosity.[20, 33, 34]

Electrode Coatings

First Herres[1] and later Hatherly[8] have classified the various types of electrode coatings for electric arc welding according to their effect on porosity through the water vapor (Eq. 1) or carbon monoxide reaction (Eq. 2):

(*A*) Bare wire electrodes or electrodes with coatings high in iron oxide. Weld beads made under the oxidizing conditions provided by these electrodes will be high in oxygen and low in hydrogen. Thus, the formation of porosity will be due to the carbon-oxygen reaction. As mentioned earlier the formation of cavities in bare wire welds can also be caused by the release of nitrogen during solidification.

(*B*) Electrodes with heavy-cellulose type coatings. Since with this type of electrode coating, the arc atmosphere consists largely of hydrogen, the weld metal should be high in hydrogen and low in oxygen. While the water vapor reaction can occur, porosity should be slight unless further oxygen is supplied to the weld metal, as from rust or scale.

(*C*) Electrodes with coatings containing both cellulose and iron oxide. In this case, the weld metal is high in both hydrogen and oxygen. Consequently, the increase in the water vapor reaction may produce porosity.

(*D*) Electrodes with lime base or mineral type coating. The amount of porosity obtained when welding with this type of electrode depends largely upon its moisture content. Herres[1] has demonstrated that the number of voids is at a minimum for a critical moisture content in the electrode coating. If the coating does not contain any absorbed or combined moisture, the weld metal will be low in hydrogen but relatively high in oxygen due to oxidation by CO_2 from the limestone in the coating. Here any porosity will be the result of the carbon-oxygen reaction. According to Herres,[1] addition of a small quantity of moisture to the mineral-type coating will decrease the oxygen content of the weld metal and thus prevent the carbon-oxygen reaction without providing sufficient hydrogen to cause appreciable porosity by the water vapor reaction. However, when larger amounts of moisture are added to the coating, oxygen, as well as hydrogen, becomes available to the weld metal, and the resulting water vapor reaction may produce a large number of voids. This has been verified by Agnew, Stirling and Campbell[35] who obtained extremely porous welds with humidified low-hydrogen (lime-base) electrodes. Christensen[6] has attributed the porosity caused by moisture in lime-base coatings to the reaction of small oxide inclusions in the weld metal with excess hydrogen from the water vapor. It has also been noted[29] that small additions of cellulose to a lime-base coated electrode caused a considerable amount of porosity in the welds. Again, this may be due to the water vapor reaction.

The promotion of porosity by cellulose-coated electrodes, in contrast to mineral-coated electrodes, where sulfur or selenium is present in the weld has already been discussed.

Role of Deoxidizers

Early investigators[19, 36] recognized the importance of deoxidizing elements in preventing the evolution of gas and the subsequent formation of porosity during welding. Blomberg[36] considered the problem of porosity in weld metal to be similar to that of blowholes in steel castings and gave as a solution the addition to the weld metal of Al, Si and Mn in order of decreasing effectiveness. Since then, many[3, 16, 37] have come to appreciate the relation between incomplete deoxidation and the formation of voids in weld metal, and Ti, Zr and V have been added to the list of effective deoxidizers added to the weld metal via filler rod, core wire, elec-

trode coating or base plate. Sekiguchi[28] has recently advocated the use of steel core wires for coated electrodes containing quantities of deoxidizers, such as Mn and Si, that are sufficient to insure forced deoxidation. In the inert-gas shielded arc process of welding mild steel, it has been strongly emphasized that weld soundness depends upon the presence of adequate deoxidizing elements.[20, 23, 24]

Some investigators[6, 27] have claimed that metallic deoxidizing agents in welds made with cellulose-coated electrodes may prove deleterious by forming oxide inclusions which react with hydrogen to form gas cavities. Andrews[15] has observed a series of voids associated with titania inclusions in highly reduced weld metal where every possible source of hydrogen was eliminated. He has ascribed this porosity to the reaction of carbon with the oxide inclusions.

Surface Contaminants

The effect of moisture, grease or paint on the surfaces being welded has already been mentioned as a possible cause of porosity through the absorption and release of hydrogen. Rust and scale, when present on steel plates, act as a source of oxygen for the weld metal and may in this way contribute to the formation of voids via the water vapor or carbon-oxygen reactions.

Current

Jenks[20] was one of the first to notice that the occurrence of porosity in weld metal was associated with high values of welding current. In welds made with E6011 and E6013 type electrodes, Christensen[6] observed a fairly large number of voids which he believed were due to the use of too high a welding current. In general extraordinarily high welding currents increase the temperature of the weld pool and thereby increase its solubility for oxygen and other gases. The use of high current densities also decreases the drop size and thereby increases the reaction between the metal droplets and gases present in the arc. This was shown by Losana (reported by Fast[2]) who found that the oxygen and nitrogen content of weld metal deposited with bare rods in air increased as the electrode diameter decreased.

In the sigma welding of mild steel, it has been found[20] that the porosity increases with increasing current density and that to produce sound welds, the current density should be appreciably less than 98,000 amp/sq in. (300 amp on $^1/_{16}$-in. electrode).

Arc Voltage and Arc Length

Not much has been reported about the effect on porosity of arc voltage or arc length within the range of normal welding conditions. It has been stated[20] that very low voltages (less than 26) will lead to porosity in the welding of mild steel by the sigma process if the arc is not centered within the gas shield.

Welding Speed

The formation of voids can easily be caused by the use of too fast a welding speed. In a study of the sigma welding of mild steel[20] where the travel speed was varied from 5–35 in./min, there was no porosity observed with travel speeds of 15 in./min and under. At a speed of 20 in./min, magnetic disturbances of the arc were sufficient to cause porosity, and at speeds greater than 20 in./min, there was scattered porosity, as well as a lack of proper fusion.

Cooling Rate

The influence of cooling rate on the formation of gas cavities in weld metal was recognized at an early date by Jenks[20] who observed that the weld metal must be heated sufficiently to allow for the escape of gases during cooling. The validity of this observation was recently confirmed in the tungsten electrode, inert-gas shielded arc process[22] where the intensely localized application of heat and rapid welding speeds produced such quick freezing of the molten steel that evolved gases had no chance for escape. Perhaps the best illustration of the effect of sudden cooling is the porosity commonly noted at the weld crater. While the use of a slow cooling rate is usually effective in minimizing porosity, it is no guarantee against the formation of voids where there are strong gas-forming tendencies present in the weld metal.[19]

Weld Metal Temperature and Viscosity

Although increasing the temperature of the weld metal decreases its viscosity and thus favors the escape of gas bubbles from the melt, it also favors an increased solution of gases in the molten metal. Therefore, in decreasing the number of gas cavities, an increase in the temperature of the weld metal is only desirable in those cases where it results in a slower rate of cooling.[26]

Multipass Welds

The difficulty of producing perfectly sound multipass deposits in heavy plate with either the "hot" or rutile-type electrode has been mentioned by Andrews.[15] Christensen[6] has discussed the "well-known" porosity in multipass welds made with the E6013-type electrode and suggests it was caused by the carbon-oxygen reaction.

Quantity of Gas Evolved

Fast[2] has suggested that porosity in weld metal may be caused not only by an extremely strong evolution of gas but also by a reduced evolution of gas where such evolution is delayed or occurs fairly slowly. That slowly evolved gasses are more easily encased by solidifying metal has already been shown to be true for the solidification of steel ingots.[29]

PHYSICAL CHARACTERISTICS OF POROSITY

During the solidification of weld metal, gas bubbles are usually formed at the liquid-solid interface where they remain until they have grown large enough to make their escape upward through the melt. If the rate of detachment and ascent to the surface is slower than the advancement of the interface, then the bubbles are enmeshed in the solidifying metal to produce gas cavities. The size of these cavities can vary from mere pinholes to large voids and will be governed by the amount of gas evolved and the conditions of solidification. While porosity is generally considered to consist merely of rounded or globular voids having a smooth bright interior, the physical form of gas cavities can often afford some insight into the mode of their generation.

The voids in weld metal often take an elongated or pear-shaped form[36] with their axes perpendicular to the solidifying surface or fusion line. It has been suggested[1, 5] that the diffusion of gases into bubbles once they are formed enables them to expand and keep pace with the solidifying metal. Such a hypothesis would explain experiments[19] where a carbonyl iron core wire was used to weld in air both bare and with a cellulose coating and produced angular voids, but when used to weld in argon as a bare rod produced almost spherical cavities. The formation of the angular voids can be explained on the basis of nitrogen diffusion (bare rod in air) and hydrogen diffusion (coated rod in air) into bubbles formed by the carbon-oxygen reaction. Another type of voids with alternate constrictions and expansions has been aptly described as "worm-hole" porosity. Occasionally, an interdendritic form of porosity is observed when the weld metal has cooled very rapidly or when the amount of gas present has just barely exceeded the solid solubility.

Where highly irregular shaped voids are encountered or where the cavities are isolated in small groups, they are probably the result of unstable welding conditions. According to Andrews,[15] an unstable arc may even result in the simple mechanical entrainment of air in the weld.

PREVENTION OF POROSITY

One of the most obvious means of avoiding porosity is to prevent the weld metal from dissolving gases or reacting with them. This may be accomplished by (1) effectively shielding the weld pool from contact with the atmosphere and other gases capable of initiating porosity and (2) eliminating gas-producing impurities from the arc through the use of moisture-free welding materials and properly cleaned surfaces. However, even the above precautions will not prevent gas evolution where the reactants for Equations 1 and 2 and the required driving force are already present in the welding electrode or base plate. In such cases, the best corrective is the use of strong deoxidizers to combine with the oxygen present and thereby immobilize the gas-producing reactions.

It goes without saying that normal welding conditions are an essential requirement for the production of sound welds; excessive current, short arcs and extreme welding speeds should be avoided. Usually, the number of gas cavities is reduced by those factors which tend to delay the onset of solidification; i.e., relatively high-heat inputs and preheating.[8] However, care should be exercised to avoid overheating and to provide for slower, more uniform welding so that the weld metal solidifies in a steady, progressive manner rather than intermittently in large steps.[28, 36]

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Evaluation of the Circular-Patch Weld Test

The circular-patch weld test is a good means of evaluating weldability in so far as weld metal and base metal cracks during welding, cooling and subsequent aging are concerned

by John E. Hockett and L. O. Seaborn

Abstract

The applicability of the circular-patch weld test as a means of determining weldability was investigated. The type of specimen used in this test has high biaxial residual stresses which promote cracking. Exploration of the possibility of utilizing such a test to predict probability of cracking or brittle behavior under external load, as in service, was the primary objective of this investigation. This was done by bending four series of unnotched Unionmelt-welded patches and one set of manually welded patches at several temperatures to determine what effects welding variables had on transition temperature. The transition temperatures of the Unionmelt-welded specimens were, in general, unaffected by the welding procedure employed. These temperatures were lower than that of the manually welded series. The energy to fracture, maximum bend angle and maximum deflection were markedly affected by welding variables.

INTRODUCTION

ONE of the major problems constantly faced by the welding industry today is the question of weldability. Designers, welding engineers and welders frequently have widely different conceptions of weldability. Füchsel[1] stated "Perfect weldability signifies that welding process, filler metal (if any), and base metal have combined to produce a joint having the same properties as a duplicate of the joint machined from a single block." This is virtually impossible in most practical applications. On the other hand, Paris[2] wrote, "A steel is weldable if any process exists by which satisfactory welds can be made." Such a definition is so general as to be interpreted as meaning that all steels are weldable, which may be so, literally, but is not so from a practical standpoint. Ford[3] expressed the opinion that weldability is a function predominantly of the quality of the steel to be welded, while other writers think that filler rod and filler metal are the principal factors in determining weldability.

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Spraragen and Claussen[4] expressed the opinion that a definition of weldability should contain a description of the weld, or its opposite—what it should or should not be—and a means of measuring the ease or completeness of fulfillment of the description—usually one or more tests. In a series of articles on weldability,[4–10] Spraragen and Claussen considered the prominent factors involved in weldability tests to be base metal cracks, weld metal cracks and cracks and brittleness under external load. Approximately forty tests were described in these articles, published in 1941, and many tests have been developed or proposed since then.

One weakness in the majority of laboratory tests developed to measure weldability is the lack of residual stresses in the specimens. The poor correlation between laboratory tests and service failures may, in part, be due to the differences in residual stress. Greene[10] suggests that reasons for this lack of correlation are: (1) The use of small specimens, (2) the extreme difficulty of isolating the effects of residual welding stresses from other metallurgical factors and, (3) the necessity of testing sound welds above the yield strength to produce failure at atmospheric temperatures. It is suggested that use of a circular-patch weld test partially corrects for these shortcomings. Such a test is used by the United States Navy for electrode qualification.[11] In this application quantitative correlation may be unnecessary because residual stresses developed by the circular-patch test are equal to or greater than those encountered in service.

In investigating various procedures for shielded-metal-arc welding an air-hardening alloy steel, Wooding[12] utilized a circular-patch test. He mentioned that restraint imposed upon the weld could be varied by changing outside dimensions of the plate or the mean diameter of the circular groove weld. At a later date Wooding wrote[13] that he knew of no quantitative evaluation of residual stresses in circular patch tests. Levy[14] investigated the residual stresses of various patch diameters and plate size in 1-in. mild steel plate. He concluded that a range of patch diameter to plate width ratios from 0.200 to 0.300 resulted in residual stresses of the order of the yield

strength of the base plate, and occasionally higher. Also, he observed that, using patch diameter to plate width ratios in the critical range specified, a 12-in. sq plate was an optimum size, attaining residual stresses of about the same magnitude as larger plates, but of greater magnitude than smaller plates.

The circular-patch-type weld test, because of the restraint imposed on the weld and heat-affected zone, is usually considered to be an adequate test to determine weldability. For a given set of welding conditions, the presence or absence of base metal cracks and weld metal cracks can be determined by visual, radiographic and other inspection methods. It remains to be determined whether this type of test can give satisfactory evidence on which to predict brittle behavior under external load.

This investigation was conducted to determine the effects of changing arc voltage, current and welding speed on the mechanical behavior of circular patch specimens. Several 5-in. diam patches were cut from the center of 12-in. sq, 1-in. thick mild-steel plates. These patches were Unionmelt welded back into the plates in four series: low voltage, high voltage, low-current low-speed two-pass, and high-current high-speed two-pass. A hand backing weld was used. Temperatures were determined at several distances from the weld during cooling in one plate of each Unionmelt series. A fifth series of patches was hand welded in place for comparison. The plates were bent as simple beams at several different temperatures to determine the effect of the above-mentioned variables on the transition temperature of the steel. A pronounced effect on transition temperature produced by a change in welding conditions would indicate that this circular-patch test might be useful in predicting serviceability.

SPECIMEN PREPARATION PROCEDURE

Several 12-in. sq plates were cut from one large plate mild steel, originally 7 ft wide, 22 ft long and 1 in. thick. Chemical analysis of the steel is: Carbon 0.24%, manganese 0.50%, chromium 0.05%, nickel 0.08%, copper 0.07%, aluminum 0.04%, silicon 0.07%, sulfur 0.05% and phosphorus 0.045%.

The circular patches were flame cut from the plates on a turntable. The edges of the hole and patch were torch scarfed.

It was decided to use Unionmelt welding to weld the patches back in place in order to eliminate such variables as are usually introduced by hand welding. Rather than using a metal backing plate, which would subsequently have to be machined off, a hand-weld backup was used. The double-V groove prescribed[18] for Unionmelt butt welds with hand-weld backup was modified to the form shown in Fig.1 to facilitate the hand welding.

The hand welding procedure consisted of four steps: (1) Tack-welding the patch in place at two points, (2) starting at a third position, equidistant from the two in step 1, welding a bead deep in the land at the bottom of the 90-deg V-groove, (3) filling in the 90-deg V-groove in the normal manner, (4) welding a bead deep into the land at the bottom of the 60-deg V-groove, fusing with the previous bead. F6020 electrodes were employed for the hand welding.

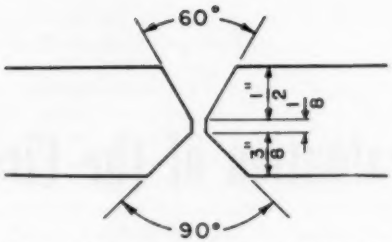

Fig. 1 Weld preparation used for investigation

The Unionmelt welds were made with 16-ft lengths of 5/32-in. Oxweld No. 36 welding rod and No. 80 Unionmelt flux. Typical composition of the welding rod is: 0.15% carbon, 1.90% manganese, 0.05% silicon, 0.05% sulfur and 0.045% phosphorus. The welding was accomplished by suspending a standard Unionmelt welding head with air-driven motor above the turntable. The plate to be welded was clamped to the turntable with spring clips. Changes in turntable speed were made by changing the line voltage to the driving motor.

Reverse polarity direct current was used to prevent excessive penetration found with straight polarity. The current was controlled by adjusting the speed of the air-driven motor which fed the rod. Voltage was maintained constant by a special control device on the welding generator. Flux was ladled onto the groove by hand.

Welds were made in four series. Voltages, currents and welding speeds are listed in Table 1. One plate of each series was used to measure the temperature at various distances from the edge of the weld from the time the electrode reached the temperature-measurement position until the plate cooled to about 300° F. Temperature measurements were taken one-eight revolution from the start of welding.

TABLE 1

Series	*Current, amp*	*Voltage, v*	*Welding speed, ipm*	*Pass No.*
I	600 ± 25	30 + 1 − 0.5	6 + 0.2 − 0.4	1
II	600 ± 25	38 + 0.5 − 1	6 + 0.2 − 0.4	1
III	325 + 15 − 25	38 ± 1	6 + 0.2 − 0.4	1
III	325 + 15 − 25	38 ± 1	6 + 0.2 − 0.4	2
IV	600 ± 25	38 ± 1	12 + 0.4 − 0.8	1
IV	600 ± 25	38 ± 1	12 + 0.4 − 0.8	2

Four to six thermocouples were imbedded in each plate. These were connected to a manual selector switch, which was connected by two leads to a General Electric Photoelectric Recorder. Temperature measurements were made after each pass of the two-pass welds.

For comparison, a series of hand-welded specimens was also tested. E6010 electrodes, $^{5}/_{16}$ in. diam, provided the filler metal for these specimens. The current employed was 190 amp; the voltage was 28 ± 1 v. The specimens were not cooled between passes.

SPECIMEN TESTING PROCEDURE

Plates from each welded series and from a series of blank plates from which no patches were cut were bent as simple beams at temperatures ranging from $-98°$ F ($-72°$ C) to $+32°$ F ($0°$ C). The plates were laid on an anvil with Unionmelt weld on the bottom, or tension side. The anvil consisted of two horizontal 2-in. rollers supported at a distance of 6 in. between centers. One 2-in. bar served as a mandrel, which pressed downward on the top side of the plate—hand-weld backing side—at midspan between the two rollers of the anvil. The anvil was in a methanol-filled sheet steel tank, which was resting on the bottom table of a 400,000 lb Baldwin-Southwark Universal testing machine.

Mandrel and plate were both immersed in the methanol in the steel tank containing the anvil. The temperature of the methanol was controlled by cooling coils in the tank along its sides and ends. These coils were connected by flexible tubes to a heat-exchanger unit which is accurately described in another publication.[16]

A clip-type deflection gage was supported between two vertical steel rods, one attached to the top of the lower head and the other to the bottom of the upper head of the testing machine. The clip gage consisted of Baldwin SR-4 strain gages cemented to a flexible metal strip. A switch in the gage-recorder circuit was closed momentarily at each 10,000-lb load increment to make a pip on the deflection curve. Thus a load-deflection curve was obtained for each plate bent.

EXPERIMENTAL RESULT

Figure 2 shows the results of the bend tests in the form of curves of deflection at fracture versus temperature for the four Unionmelt, one hand welded and one unwelded series. Two unwelded plates and two welded plates, of the low-voltage series, deflected the maximum amount possible within the limitations of the bend jig, but did not fracture. All four were at maximum load or very nearly so, and were bending with little or no increase in load when the load was removed.

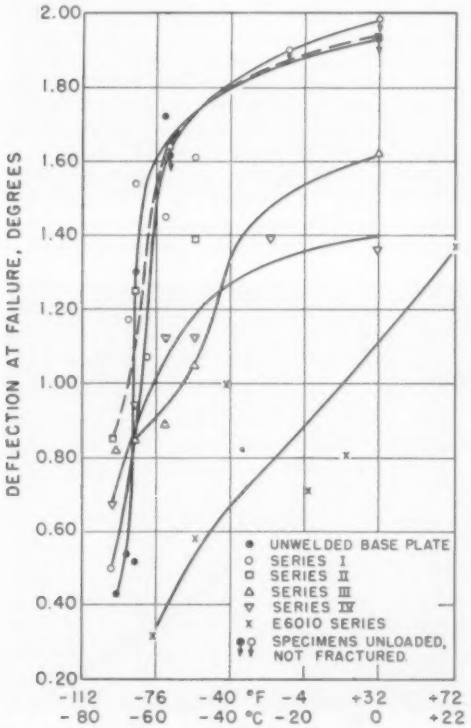

Fig. 2 Deflection vs. temperature for bend tests on circular-patch weld specimens

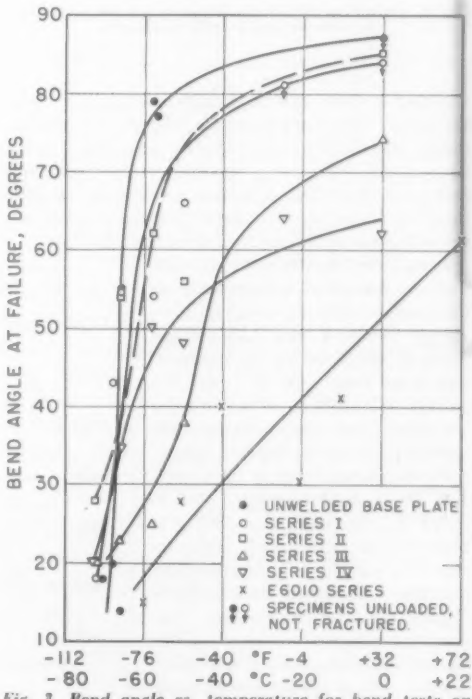

Fig. 3 Bend angle vs. temperature for bend tests on circular-patch weld specimens

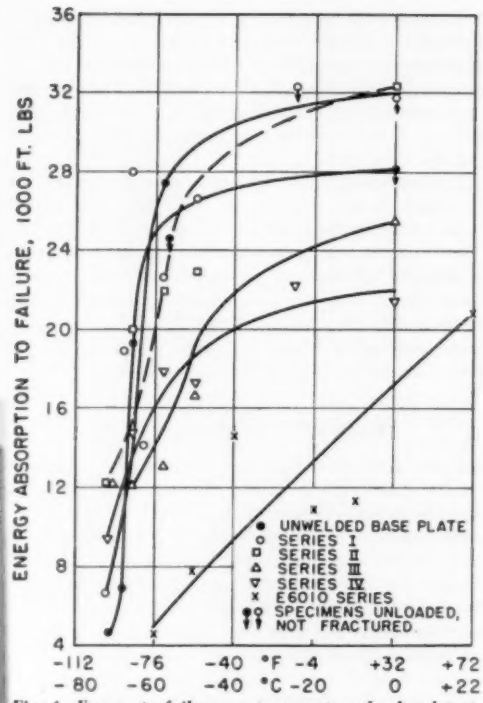

Fig. 4 Energy to failure vs. temperature for bend tests on circular-patch weld specimens

Figure 3 shows the bend angles at fracture, or at unloading, versus temperature. Figure 4 shows the energy absorbed at fracture, or unloading, versus temperature. The energy was calculated by replotting each point of the load-deflection curves from the SR-4 Recorder charts on rectangular coordinate paper and measuring the area under the curves thus obtained.

From these three figures, it appears that the transition temperatures of the unwelded base plate, and the low-voltage Series I and high-voltage Series II are all within the temperature range from −76° F (−60° C) to −94° F (−70° C). The two-pass, low-speed, low-current Series III appears to have the highest transition temperature range of the Unionmelt series, approximately −40° F (−40° C) to −58° F (−50° C). The two-pass, high-speed, high-current Series IV has an intermediate transition temperature between Series III and the other three series. The transition temperature range for the manually welded series is much higher extends over a greater range from −75° F (−60° C) to +75° F (23° C).

The fracture of an unwelded plate tested at −72° F (−58° C) was entirely cleavage: the fracture of a Series I plate tested at −96° F (−71° C) was of the cleavage type except for a narrow zone of shear type around both Unionmelt and hand backing welds. Similar fractures were found in the other series. A typical series of cooling curves, obtained while welding a Unionmelt specimen, is shown in Fig. 5.

DISCUSSION

The transition temperatures of low-voltage and high-voltage single-pass Unionmelt-welded patches apparently are approximately the same as for an unwelded plate, at least in the mild steel tested. While this speaks well for the Unionmelt welding process, it indicates that the capability of the circular patch weld test to differentiate between the low and high values of one variable, voltage, is certainly in question. There should be a detectable difference in ductility of low and high-voltage Unionmelt welds. This was shown for single-bead tests by Riches.[17]

There is some differentiation between the transition temperatures of two-pass and single-pass welds, and an appreciable difference between those of Unionmelt welds and hand welds. There is also a recognizable difference between high-current, high-speed, and low-current, low-speed, two-pass welds, the latter appearing to have the higher transition temperature; but this is not clear-cut by any means. Kinzel[18] reported that high currents with high speeds raised transition temperatures less than did low currents at low speeds. The energy absorption capacity of two-pass welds is unquestionably lower than that for single-pass welds or unwelded plate. As pointed out by Boodberg and Parker,[19] transition temperature cannot be the only criterion for evaluating service performance, for two

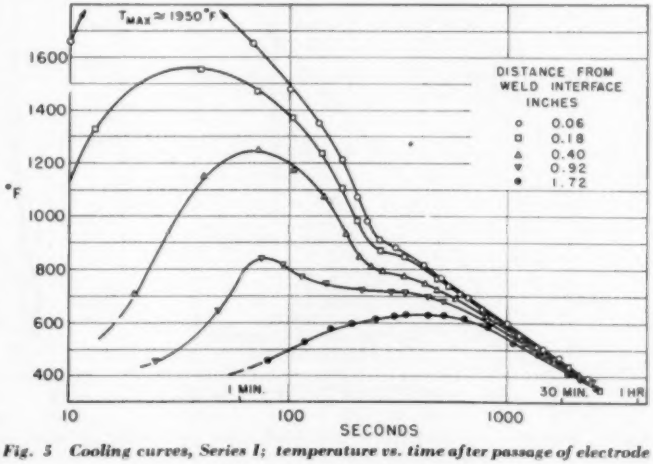

Fig. 5 Cooling curves, Series I; temperature vs. time after passage of electrode

steels with similar transition temperatures may have greatly different energy-absorption characteristics. This can be extended to include welding a single steel by two considerably different procedures.

Using ductility measurement as the criterion of transition temperature, all series of welds except the hand-welded ones had satisfactory properties, regardless of how the welding procedures were varied. This is illustrated in Fig. 6 and 7.

Figure 6 is a photograph of the tension side of a Series I plate tested at 32° F (0° C) and Fig. 7 is a photograph of a Series I plate tested at −87° F (−66° C). In both photographs cracks can be seen starting in the base plate. The weld metal remains intact except for one crack in Fig. 6, which appeared to have started in the heat-affected zone and had grown into both the weld and base metal.

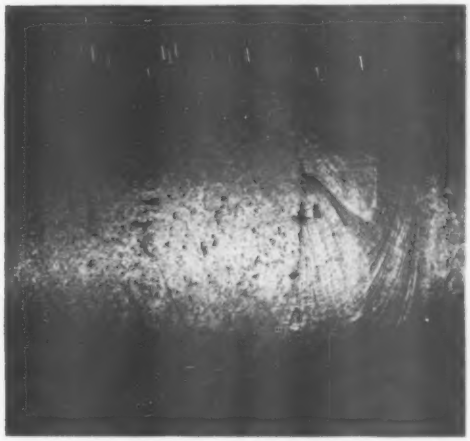

Fig. 6 Photograph of specimen from Series I bent at + 32° F showing cracks in plate and heat-affected zone × 0.6

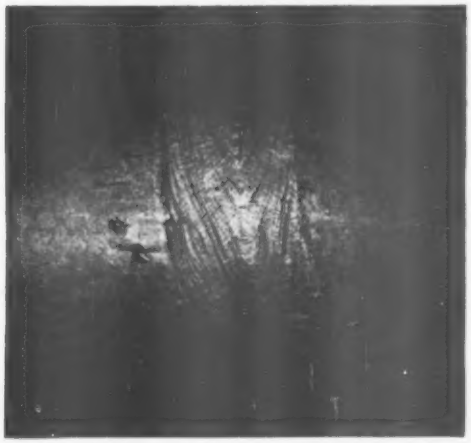

Fig. 7 Photograph of specimen from Series I bent at − 87° F showing cracks in plate. × 0.6

Using mode of fracture as the criterion for transition temperature, neither the unwelded base plate nor any of the welded plates would be satisfactory. All plates failed with a cleavage-type fracture, regardless of the amount of bending preceding failure. This corroborates the statement of Boodberg, Davis, Parker, and Troxell[20] to the effect that cleavage fracture is not necessarily an indication of a lack of plastic flow. In a discussion of the meaning of "transition temperature," Stout and McGeady[21] presented excellent arguments in favor of both the ductility and the mode of fracture criteria for determining transition temperature. For this series of tests, ductility appears to be the more significant measure of transition temperature. The smallest bend angle attained in this investigation would be considered "failure,"[22] structurally, because of the excessive dimensional changes produced by plastic flow. Hence the mode of subsequent fracture seemed inconsequential.

In general the fractures all showed a zone of shear-type fracture along the weld-base-metal interface, extending into the heat-affected zone approximately 0.10 to 0.20 in. In an attempt to find the logical metallurgical explanation for this ductile zone, cooling rates were considered. Cooling rates were obtained from the cooling curve data. These rates are plotted versus distance from the weld-base-metal interface, at the plate surface, in Figs. 8, 9 and 10, for the temperatures 1100, 1000 and 900° F, respectively. These

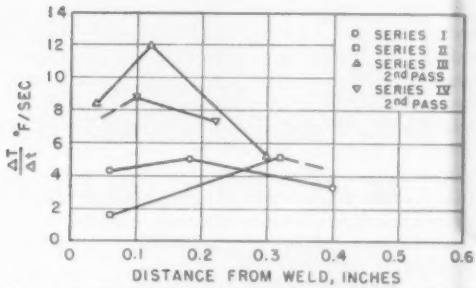

Fig. 8 Cooling rate vs. distance from weld at 1100° F

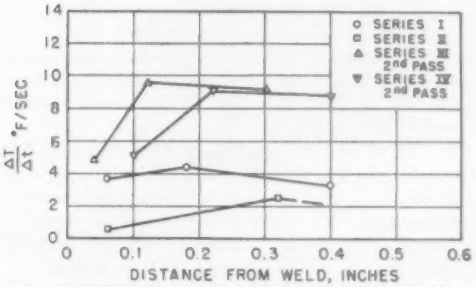

Fig. 9 Cooling rate vs. distance from weld at 1000° F

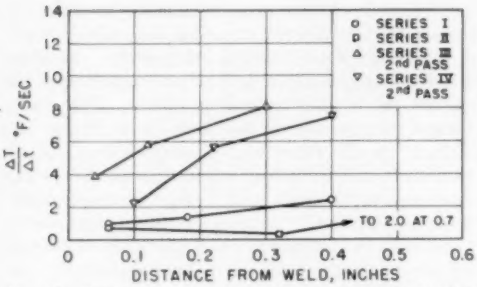

Fig. 10 Cooling rate vs. distance from weld at 900° F

three temperatures adequately cover the temperatures at which the "knee" of the time-temperature-transformation curves for mild steel exists.[28] Most of the points to the extreme right-hand side of these curves are of little significance as the metal at such distances from the welds did not reach the austenitizing temperature.

Of considerable significance is the fact that at no point in the heat-affected zone was there a cooling rate greater than 12 to 15° F per second, even in the hand-welded series. Such a cooling rate is indisputably too low to produce a brittle metallurgical structure. The zones of shear-type fracture mentioned above indicate a more ductile structure than in the weld or in the unaffected base metal. The structure in these zones was found to be Bainite in all cases.

As previously mentioned in the introduction, Wooding[12] used a circular-patch test to select welding procedures for air-hardening alloy steels. Excellent results were obtained as to weld metal and base metal cracking, but predictions of serviceability were based more on experience with a similar steel than with any quantitative results of the test. The use of this test to determine transition temperatures would involve considerably more expense than other simpler tests. As the transition temperatures were not markedly affected by welding variables, it would seem advisable to restrict the use of the circular patch test to weldability evaluation.

CONCLUSIONS

1. The circular-patch weld test under investigation is a good means of evaluating weldability in so far as weld and base metal cracks during welding, cooling and subsequent aging are concerned. This is due, principally, to the quantitative control of biaxial residual stresses.

2. The mechanical testing of circular-patch welds by bending as a simple beam at several temperatures is a reasonably accurate method of determining transition temperatures. The value of such transition temperatures in differentiating between different welding conditions and/or reflecting their effects is dubious.

3. Because of an inherently low cooling rate, circular patch weld tests are not appropriate for the production of brittle metallurgical structures in commonly used thicknesses of carbon and low-alloy structural steels when submerged arc welding is employed. This is also true for hand-welded specimens providing the specimens are not cooled between passes.

4. This circular-patch weld test, utilizing submerged arc welding, is not an effective means of determining "serviceability," defined as probability of cracking or brittle behavior under external load.

ACKNOWLEDGMENTS

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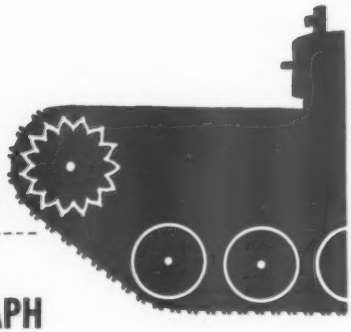

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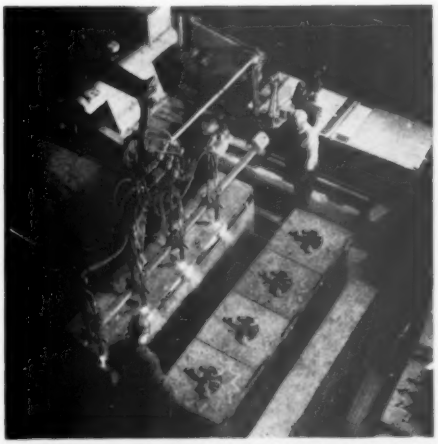

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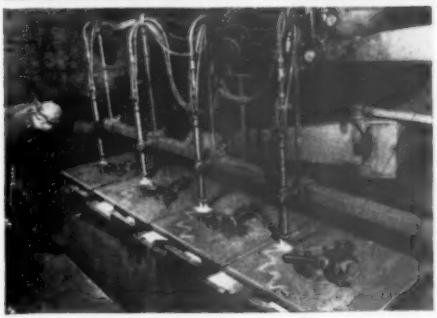

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